

THE STRATIGRAPHY OF THE NATAL GROUP

by

C.G.A. MARSHALL

N.I. 14 accompanying maps in map cabinet M.684/043 - M.684/056
2. 3 loose charts in back pocket.

Submitted in fulfilment of the
academic requirements for the degree of
Master of Science
in the
Department of Geology,
University of Natal

Pietermaritzburg

1994

ABSTRACT

Research for this project involved the first systematic field and laboratory investigation over the entire known portion of the Natal Group depositional basin, from just north of Hlabisa in the north, to Hibberdene in the south, and, on a reconnaissance basis, as far south as the Mtamvuna River near Port Edward.

The development of a stratigraphy for the Natal Group is traced through the work of previous researchers, who worked in specific areas. The SACS compilation was inadequate, and this unsatisfactory situation was addressed in presenting the first workable stratigraphic subdivision of the Natal Group for the whole of the basin. There are two proposed formations, each representing a cycle of sedimentation - a lower Durban Formation and an upper Mariannahill Formation. These are subdivided into the Ulundi, Eshowe, Kranskloof, Situndu and Dassenhoek Members, and the Tulini, Newspaper and Westville Members, respectively. They are generally greyish red in colour, and consist of conglomerates, sandstones, siltstones and shales. The generally accepted correlation between the Natal Group in KwaZulu-Natal and what was hitherto considered as its time-equivalent in Pondoland has been disproved. Consequently, the supposed interdigitation/transition between these two assemblages, along with the hypothesis that the Kranskloof and Dassenhoek quartz-arenite Members were littoral deposits formed during a marine transgression/regression cycle, is no longer accepted.

A provenance to the northeast is proposed, based on palaeocurrent data. Pan-African mountain-building in what is now Mozambique provided molasse sediments which were laid down in an elongate (NE - SW) foreland graben basin. The age of this was determined as 490 Ma, from $^{40}\text{Ar}/^{39}\text{Ar}$ step-heating on micas extracted from argillaceous samples. Contemporaneous volcanism, as reflected in the presence of volcanic glass (sericitised) shards, is reported. The Natal Group is a molasse deposit, derived some 490 Ma ago from a Pan African orogenic event in southern Mozambique, and deposited in a foreland graben, the Natal Trough, during continued subsidence. Activity of this trough is seen to have continued from Pan African to Permian times. This assemblage rests on the basement, and is overlain by the Dwyka Group. Only part of the basin survives on the

African continent, the unknown portion being removed during the fragmentation of Gondwana. The southern limit of the Natal Group is at the Dweshula High, near Port Shepstone, which, together with basin tilting, is seen to have been instrumental in causing the deposition of this assemblage.

It is suggested that fluvial activity and debris flow processes led to the deposition of the conglomerates of the Ulundi, Tulini and Westville Members, whereas braided rivers of the Platte and Bijou Creek types deposited the arenaceous and argillaceous sediments which now constitute the other members. The climate was probably semi arid, with ephemeral streams. Shape parameters of the conglomerate clasts point to a fluvial environment.

The dividing-line between monomict (quartz) Facies A to the south, and polymict Facies B to the north, of the Tulini Member, was found to coincide with the edge of the craton in this area.

The common occurrence of pressure solution phenomena is described. The tensile strength of fractured quartzite clasts in the Ulundi Member is used to estimate a minimum thickness for the Natal Group of 1300 to 2600 m - considerably greater than the present thickness. This estimate supports the hypothesis that much of the Natal Group was removed by erosion during the 200 million year period between the cessation of Natal Group deposition and the onset of Dwyka glaciation, and indeed, by the glaciation itself. The Westville Member is thus seen as the basal unit of a third cycle of sedimentation, all of which, except the remnants of the Westville Member, have been eroded away.

PREFACE

I, CHARLES GERALD ANTHONY MARSHALL, hereby declare that the research described in this dissertation was carried out **in the field** and at the Geological Survey, Pietermaritzburg, under the auspices of the Department of Geology, University of Natal, Pietermaritzburg, from October 1986 to July, 1994, under the supervision of Professor V. von Brunn.

This dissertation and accompanying maps represent original work by the author, and have not been submitted , in whole or in part, to any other university for the purpose of a higher degree. Where reference has been made to the work of others, it has been duly acknowledged in the text.

A handwritten signature in black ink, appearing to read 'C.G.A. Marshall', written in a cursive style.

C.G.A. MARSHALL

ACKNOWLEDGEMENTS

The author is indebted to the Department of Mineral and Energy Affairs for a bursary loan which partially financed the first year's fees, and to the Executive Officer of the Council for Geoscience for allowing the author to use the data, time and facilities to complete the project. Mr Eric Filmalter determined the U.C.S. of some quartzite boulders. Mrs Helena Alexander helped with the compilation of tables and with the intricacies of word-processing. Dr Doug. Cole is thanked for his ready help and advice concerning the statistics of directional data. Dr C.J. van Vuuren is thanked for proposing that the Natal Group project be directed towards obtaining a post-graduate degree. Dr John Dunlevy of the University of Durban Westville is thanked for his willing help in preparing the ternary diagrams. Discussions with colleagues Drs Dave Roberts, Bob Thomas, Greg Botha, and Albert Thamm were immensely helpful, and the author wishes to express his gratitude. The constant help, supervision and provision of relevant references to the literature by Professor Vic. von Brunn are much appreciated. The South African Police Services at Kranskop, Harburg, Mid Illovo and Sawoti, Mr James of Hazelmere Dam and Mr Upfold of Shongweni Dam are thanked for allowing the author to camp on their premises. The author is also grateful for the support, help and companionship of Enock Mkhize, Petros Silamulela, Misron Ngcobo and Isaac Ndlovu who at various times accompanied him in the field. Without the patience, understanding and support of the author's wife and family, this project would not have been possible. The willing help of Ena Rhind, Trina and Tanja Marshall and Ronald Munro, who coloured in some of the maps, and Olive Anderson who drew several diagrams, is gratefully acknowledged. Lastly, but by no means least, the author is conscious of, and deeply grateful for the guidance and protection given him by the Lord Jesus (Who created all things) and who said, "*Lo, I am with you alway, even unto the end of the world.*"

CONTENTS

ABSTRACT	ii
PREFACE	iv
ACKNOWLEDGMENTS	v
LIST OF FIGURES	xi
LIST OF TABLES	
1. INTRODUCTION	1
1.1 OBJECTIVES	1
1.2 SCOPE	3
1.2.1 GEOLOGICAL MAPPING	3
1.2.2 VERTICAL SECTIONS	6
1.2.3 SAMPLING PROGRAMME	6
1.3 PREVIOUS WORK	7
1.3.1 STRATIGRAPHY	7
1.3.2 THICKNESS	8
1.3.3 PALAEOLOGY	8
2. STRATIGRAPHY	10
2.1 EARLY STRATIGRAPHIC SUBDIVISIONS	10
2.2 RHODES AND LEITH (1967)	12
2.3 KINGSLEY (1975)	12
2.4 THE SOUTH AFRICAN COMMITTEE FOR STRATIGRAPHY (SACS), 1980	13
2.5 ROBERTS, 1981.	15

2.6 PRESENT WORK	16
2.6.1 DURBAN FORMATION	17
2.6.2 MARIANHILL FORMATION	20
2.6.3 GENERAL CONSIDERATIONS	22
3. DESCRIPTION OF THE NATAL GROUP UNITS	27
3.1 DURBAN FORMATION	28
3.1.1 ULUNDI MEMBER	28
3.1.2 ESHOWE MEMBER	46
3.1.3 KRANSKLOOF MEMBER	63
3.1.4. SITUNDU MEMBER	75
3.1.5. DASSENHOEK MEMBER	80
3.2 MARIANHILL FORMATION	85
3.2.1 TULINI MEMBER	85
3.2.2 NEWSPAPER MEMBER	93
3.2.3 WESTVILLE MEMBER	99
4. CLAST MODIFICATION: NATAL GROUP THICKNESS	103
4.1 PRESSURE SOLUTION	103
4.2 PRESSURE-FRACTURING	105
4.2.1 INTERPRETATION	108
4.2.2 CONCLUSION	111
5. BASIN TECTONICS	112
5.1 INTRODUCTION	112
5.2 BASIN LIMITS	112
5.3 BASIN MORPHOLOGY	115

5.4 TECTONICS	119
5.4.1 REPOSITORY	119
6. DEPOSITION	128
6.1 INTRODUCTION	128
6.2 SEQUENCE OF EVENTS	131
6.2.1 DEVELOPMENT OF BASIN	131
6.2.2 EARLIEST DEPOSITS	133
6.2.3 DEPOSITION OF DURBAN FORMATION	134
6.2.4 DEPOSITION OF MARIANNHILL FORMATION	142
6.3 DISCUSSION	147
6.3.1 MAXIMUM THICKNESS OF THE NATAL GROUP.	147
6.3.2 SOUTHERN LIMIT OF THE NATAL GROUP SEDIMENTATION.	149
6.3.3 NORTHWARD EXTENSION OF MSIKABA FORMATION.	150
6.3.4 PALAEOCLIMATE.	150
6.3.5 CLAST SHAPE PARAMETERS	154
6.3.6 TERRESTRIAL / MARINE ORIGIN OF KRANSKLOOF AND DASSENHOEK MEMBERS.	155
6.3.7 INTERDIGITATION / TRANSITION	160
6.3.8 HAEMATITE	164
6.3.9 PROVENANCE	165
7. CONCLUSIONS	168
7.1 STRATIGRAPHY	168
7.2 FACIES AND TRENDS	168
7.3 PROVENANCE AND ENVIRONMENT	169

7.4 KWAZULU-NATAL / PONDOLAND CORRELATION	170
REFERENCES	171
APPENDICES	
APPENDIX 1. MEASURED SECTIONS	179
APPENDIX 2. GEOLOGICAL MAPS	235
APPENDIX 3. GRAIN-SIZE ANALYSIS AND COMPOSITION	237
APP-3.1 COMPOSITION	237
APP-3.2 GRAIN-SIZE	239
APP-3.3 STATISTICAL PARAMETERS	245
APP-3.3.1 FIRST MOMENT	247
APP-3.3.2 SECOND MOMENT	247
APP-3.3.3 THIRD MOMENT	249
APP-3.3.4 FOURTH MOMENT	250
LIST OF REFERENCES: APPENDIX 3.	253
APPENDIX 4. PALAEOCURRENT ANALYSIS	255
APP-4.1 INTRODUCTION	255
APP-4.2 PREVIOUS WORK	255
APP-4.3 METHODS	257
APP-4.3.1 SAMPLING PROCEDURES	257
APP-4.3.2 ANALYSIS OF DATA	257
APP-4.3.3 DISCUSSION OF RESULTS	262
LIST OF REFERENCES: APPENDIX 4	276
APPENDIX 5. CLAST SHAPE PARAMETERS	277

LIST OF FIGURES

Fig.	Description	Page
1.1	Map of localities mentioned in text	2
1.2	Distribution of Natal Group and Msikaba Formation	4
2.1	Stratigraphic comparison	11
3.1	Ulundi Member conglomerate resting on ferruginous Pongola Supergroup argillite	29
3.2	Stratified Ulundi Member overlying basement and overlain by Dwyka Group	29
3.3	Imbricated, well-rounded clasts in monomict Ulundi Member conglomerate	31
3.4	Shape parameters and flatness vs sphericity, Ulundi Member	33
3.5	Clast-supported Ulundi Member conglomerate with flat-lying clasts, transported by hyperconcentrated flood flow	34
3.6	Base of Ulundi Member. Note debris-flow with flat-lying clasts	34
3.7	Base of Ulundi Member, southeast of Babanango, showing angular, tabular clasts with horizontal orientation..	35
3.8	Ulundi Member conglomerate with angular clasts northeast of Nkandla	35
3.9	Orientation of Ulundi Member clasts	37
3.10	Composition of Ulundi Member sandstones	39
3.11	Ulundi Member conglomerate with interbedded shale	40
3.12	Geological map of Loliwe palaeotalus deposit	41
3.13a	Loliwe palaeotalus deposit	43
3.13b	Exhumed palaeokrans of Pongola Supergroup with modern talus	43
3.14	Ulundi Member conglomerate from near southern limit of basin	45
3.15	Isopach map of Eshowe Member, showing limit of Ulundi Member	47
3.16	Eshowe Member overlying basement granite unconformably, and conformably overlain by Kranskloof Member	48
3.17	Small-pebble conglomerate lens near base of Eshowe Member	50
3.18	Rip-up clasts of purple mudrock in Eshowe Member sandstone	50
3.19	Composition of Eshowe Member sandstones	52
3.20	Very coarse-grained sandstone with orthoclase imparting red colour	53
3.21	Thin beds of shale in Eshowe Member	53
3.22	Eshowe Member sandstone with interbedded shale and siltstone	55
3.23	Eshowe Member resting on basement granite and overlain by resistant Kranskloof Member	57
3.24	Set of planar cross-beds in excess of 2 m thickness	59
3.25	Trough cross-bedding in Eshowe Member, NW of Eshowe	59
3.26	Scour channel filled with coarse sandstone and rip-up clasts	60
3.27	Slump structure in Eshowe Member, a few metres above base	60
3.28	Convolute bedding in Eshowe Member	61
3.29	Internal structure of a sand volcano (water escape structure)	62
3.30	Isopach map of the Kranskloof Member	64
3.31	Typical Natal Group krans formed by Kranskloof Member overlying Eshowe Member, in turn overlying basement granite. Note vertical cleft	65

3.32	Composition of Kranskloof Member sandstones	68
3.33	Photomicrographs showing dust rim on original quartz grains	69
3.34	Thin, lenticular shale lenses in Kranskloof Member quartz-arenite	71
3.35	Roof of Noodsberg cave at contact between Tulini and Kranskloof Members	73
3.36	Isopach map of Situndu Member	76
3.37	Composition of Situndu Member sandstones	79
3.38	Shale lining (30 cm thick) to scour channel filled with sandstone	81
3.39	Situndu Member with rip-up clasts probably derived from shale lining in Fig. 3.38	81
3.40	White clay drapes on bedding and on foresets, Situndu Member	82
3.41	Isopach and palaeocurrent map of the Dassenhoek Member	83
3.42	Composition of Dassenhoek Member sandstones	86
3.43	Isopach map of Tulini Member, showing sampling positions (B to M), distribution of Facies A and B, and Tugela Thrust Front	87
3.44	Tulini Member clast- to matrix-supported conglomerate	90
3.45	Facies B conglomerate, Tulini Member	92
3.46	Pale grey Newspaper Member sandstone at Nhlavini	94
3.47	Composition of Newspaper Member sandstones	96
3.48	Large scour channel in Newspaper Member filled by plane cross-bedded sandstone	98
3.49	Matrix-supported, polymict, pebble conglomerate, Westville Member	101
3.50	Shape parameters and flatness vs sphericity - Mntamtanto	102
4.1	Ulundi Member quartzite clast modified by pressure solution	104
4.2	Monomict nature, close-packing, pressure solution and fracturing	106
4.3	Ulundi Member conglomerate with abundant matrix and no pressure solution	106
4.4	Pressure solution followed by pressure fracturing of quartzite clast	107
5.1	Ndindindi Ridge of Archaean quartzite in background, south of Nkandla, showing high palaeorelief. Krans in middle foreground is Ulundi Member conglomerate	117
5.2	Glaciated pavement on Kranskloof Member at Ifume, Natal South Coast. Ice flow direction coincides with trough cross-bedding axis (Photo V. von Brunn)	125
6.1	Sequence of events in the Natal Group depositional basin	132
6.2	Clasts consisting of Natal Group in Dwyka Group diamictite, resting on Natal Group (Photo V. von Brunn)	148
6.3	Patchy iron-staining of Msikaba Formation quartzite, derived from surface weathering of ferruginous minerals in the quartzite	153
6.4	Longitudinal section through Rock of Gibraltar, Oribi Gorge and Mtamvuna Nature reserve, showing Msikaba Formation overlapping Natal Group	162
APPENDIX 1		
App-1.1	Localities of vertical sections measured during investigation	180
App-1.2	Symbols and abbreviations used in measured sections	189
App-1.3	Measured Section 6 - Assegai Toll	190

App-1.4	Measured Section 51 - Nhlangwini	191
App-1.5	Measured Section 67 - Vuma Reform	193
App-1.6	Measured Section 72 - Tevreden II	195
App-1.7	Measured Section 75 - Ndlovana	196
App-1.8	Measured Section 76+78 - White Mfolozi	197
App-1.9	Measured Section 77 - Tevreden IV	200
App-1.10	Measured Section 86 - Kwaseme	201
App-1.11	Measured Section 88 - Nzimane	203
App-1.12	Measured Section 93 - Ka-Gonitshe	207
App-1.13	Measured Section 95 - Spekfontein	209
App-1.14	Measured Section 99 - Hlimbitwa	211
App-1.15	Measured Section 110 - Clantrock	213
App-1.16	Measured Section 115 - Ngcongcongcong	214
App-1.17	Measured Section 119 - Sherbrook	218
App-1.18	Measured Section 120 - Kwagqumagquma	219
App-1.19	Measured Section 125 - Table Mountain	220
App-1.20	Measured Section 132 - Mgwahumbe	222
App-1.21	Measured Section 136 - Nkwazi	223
App-1.22	Measured Section 137 - Ntabakucasha	224
App-1.23	Measured Section 138 - Hlutankungu	226
App-1.24	Measured Section 139 - Mtwalume	227
App-1.25	Measured Section 145 - Igoxa	228
App-1.26	Measured Section 146 - Gibraltar	229
App-1.27	Measured Section 151 - Mtamvuna Nature Reserve	232

APPENDIX 2.

App-2.1	Localities of geological maps presented	236
THE FOLLOWING MAPS ARE IN THE POCKET AT THE BACK		
App-2.2	Geological Map of some Natal Group occurrences in the Cato Ridge/Shongweni Area	
App-2.3	Geological Map of some Natal Group occurrences in the area north of Eshowe	
App-2.4	Geological Map of some Natal Group occurrences in the area east of Mapumulo and south of Eshowe	
App-2.5	Geological Map of some Natal Group occurrences in the areas near Nkandla and Babanango	
App-2.6	Geological Map of some Natal Group occurrences in the Hlabisa Area	
App-2.7	Geological Map of some Natal Group occurrences in the Melmoth and Ulundi areas	
App-2.8	Geological Map of some Natal Group occurrences in the Noodsberg Area	
App-2.9	Geological Map of some Natal Group occurrences in the Table Mountain (Natal) Area	
App-2.10	Geological Map of some Natal Group occurrences in the area north of Kranskop	
App-2.11	Geological Map of some Natal Group occurrences in the Dolwana Area	
App-2.12	Geological Map of some Natal Group occurrences in the area northeast of Ixopo.	
App-2.13	Geological Map of some Natal Group occurrences in the area south of	

	Highflats	
App-2.14	Geological Map of some Natal Group occurrences in the Mid-Illovo area	
App-2.15	Fence diagram showing distribution of stratigraphic units	

APPENDIX 3.

App-3.1	Grain-size moments graphs	251
a.	Skewness vs Standard error (dividing line after Friedman, 1961)	
b.	Kurtosis vs mean largest diameter	
c.	Skewness vs mean largest diameter	
d.	Standard error vs mean largest diameter	
e.	Kurtosis vs standard error	
f.	Kurtosis vs skewness	

APPENDIX 4.

App-4.1	Palaeocurrent map of the Eshowe Member	263
App-4.2	Moving average map of the palaeocurrent directions in the Eshowe Member	264
App-4.3	Palaeocurrent map of the Kranskloof Member	269
App-4.4	Palaeocurrent map of the Situndu Member and Msikaba Formation	271
App-4.5	Palaeocurrent map of the Tulini (Tu), Newspaper (Np) and Westville (Wc) Members	273
App-4.6	Map of the mean and moving averages of the palaeocurrent directions in the Kranskloof Member	274
App-4.7	Palaeocurrent map of the Newspaper Member, showing the limits of the Tulini Member	275

APPENDIX 5.

App-5.1	Shape parameter and flatness vs. sphericity - Honeygrove	278
App-5.2	Shape parameter and flatness vs. sphericity - Killiekrankie	279
App-5.3	Shape parameter and flatness vs. sphericity - Montebello	280
App-5.4	Shape parameter and flatness vs. sphericity - Mkabela	281
App-5.5	Shape parameter and flatness vs. sphericity - Baviaanskrans	282
App-5.6	Shape parameter and flatness vs. sphericity - Burleigh	283
App-5.7	Shape parameter and flatness vs. sphericity - Bulwana	284
App-5.8	Shape parameter and flatness vs. sphericity - Kwa Mbula	285
App-5.9	Shape parameter and flatness vs. sphericity - Mooiplaats	286
App-5.10	Shape parameter and flatness vs. sphericity - Carney Hill	287
App-5.11	Shape parameter and flatness vs. sphericity - Clantrook	288
App-5.12	Shape parameter and flatness vs. sphericity - Ekamanzi	289
App-5.13	Graphs of clast-shape statistics	290

LIST OF TABLES

1.1	Summary of areas mapped and vertical sections measured	5
1.2	Previously-recorded thicknesses of the Natal Group	8
2.1	Proposed stratigraphic subdivision of the Natal Group	16
2.2	Historical recognition of disparities between north and south	24
2.3	Lithological and interpretative differences between northern and southern assemblages	25
3.1	Thickness of the Ulundi Member	30
3.2	Thickness of Eshowe Member	49
3.3	Thickness of Kranskloof Member	66
3.4	Thickness of Situndu Member	77
3.5	Thickness of Dassenhoek Member	84
3.6	Thickness of Tulini Member	88
4.1	Uniaxial Compressive Strength (UCS) of Ulundi Member clasts	109
5.1	Previously-recorded palaeorelief of the Natal Group basin floor	115
6.1	Lithological differences between quartz arenites north and south of Dweshula High	164
App-1.1	List of vertical sections measured during study (8 sheets)	181-188
App-1.2	Measured stratigraphic sections included in dissertation, indicating thicknesses reported	233
App-1.3	Lithofacies and sedimentary structures, modified after Miall (1977)	234
App-3.1	Accuracy of point counting	238
App-3.2	Grain-size and composition statistics (3 sheets)	240-242
App-3.3	Grain-size distribution statistics	248
App-3.4	Verbal grain-size and sorting of the Natal Group	248
App-4.1	Natal Group palaeocurrent statistics (3 sheets)	265-267
App-5.1	Summary of Clast-shape statistics of Ulundi, Tulini and Westville Members	291

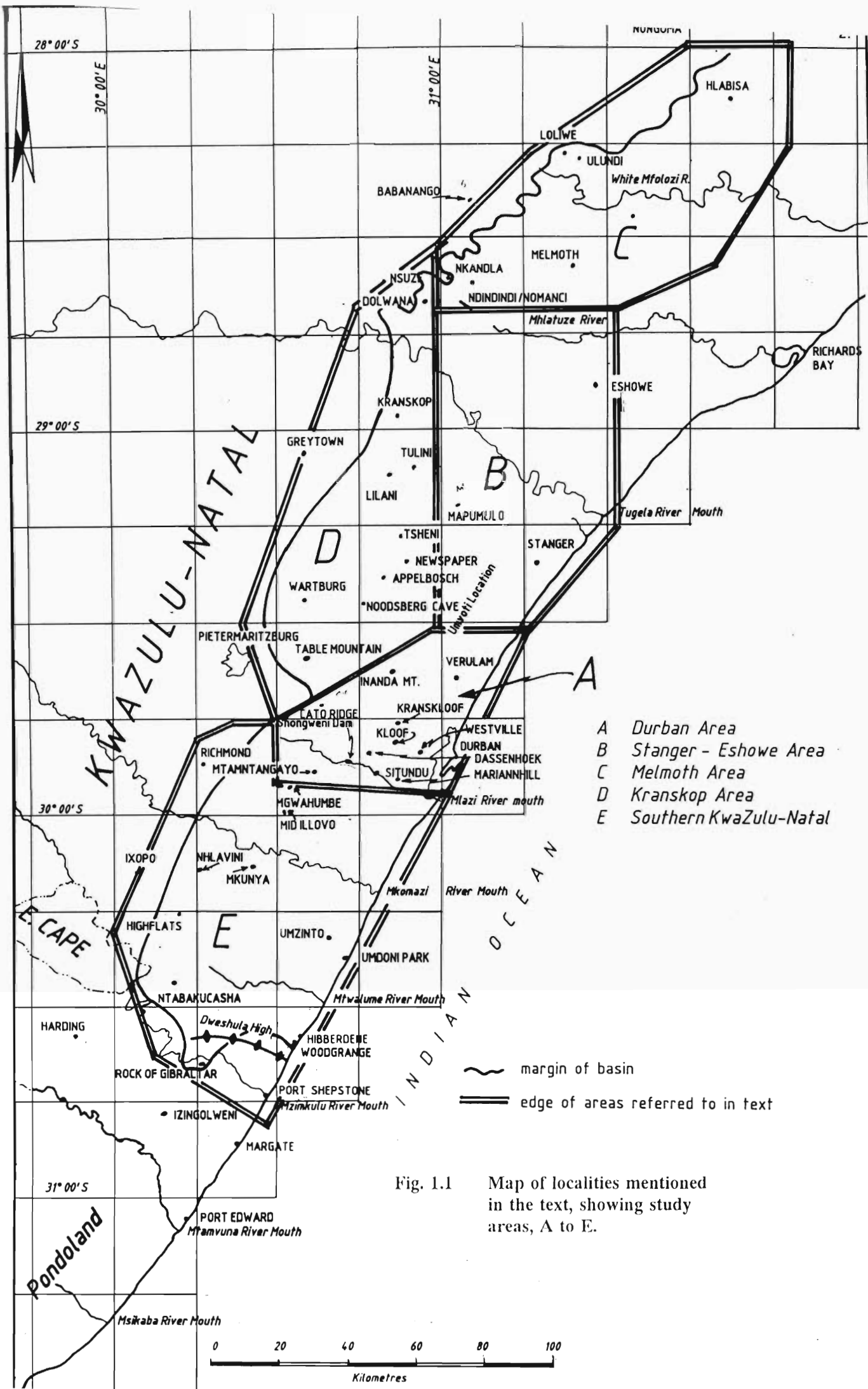
1. INTRODUCTION

The early Palaeozoic Natal Group (South African Committee for Stratigraphy [SACS], 1980), previously known as the Table Mountain Sandstone (Anderson, 1904) or Table Mountain Series (Krige, 1933), and informally as the TMS, comprises the conglomerates, sandstones, siltstones and shales which constitute the post-Kibaran, pre-Dwyka sedimentary rocks of KwaZulu-Natal and Pondoland (SACS, 1980). Because it is composed predominantly of resistant sandstone, the Natal Group forms the kranes that provide much of the rugged scenery along the eastern portion of KwaZulu-Natal and Pondoland, between Hlabisa in the North and Port St Johns in the south (Fig. 1.1). The resultant dissected nature of the terrain has provided excellent exposure of much of the Natal Group. It overlies the granitic and supracrustal Precambrian basement unconformably and is disconformably overlain by the Late Carboniferous / Early Permian Dwyka Group.

1.1 OBJECTIVES

Since Sutherland (1868) first described rocks from this succession, numerous researchers have been involved in studies on the geology of the Natal Group, but to date there has been no overall synthesis of the stratigraphy of these rocks for the whole of the region. The stratigraphic synthesis produced by SACS (1980), based as it was on the work of researchers working independently, at different times and in different areas of the basin, was not workable. The aim of this study, then, was to:

- 1.1.1 Establish a sound, workable stratigraphy for the Natal Group, and to provide a description and definition of the constituent units;



- A Durban Area
- B Stanger - Eshowe Area
- C Melmoth Area
- D Kranskop Area
- E Southern KwaZulu-Natal

Fig. 1.1 Map of localities mentioned in the text, showing study areas, A to E.

- 1.1.2 Distinguish and define various facies and trends within the Natal Group;
- 1.1.3 Consider the provenance and depositional environment of the Natal Group and its various components;
- 1.1.4 Test the validity of the accepted correlation of the Natal Group rocks in KwaZulu-Natal with those in Pondoland (Fig. 1.2), and hence with the Witteberg Group - the correlative equivalent of the Cape Supergroup in the Cape Provinces; and
- 1.1.5 Attempt to ascertain the absolute age of the Natal Group.

1.2 SCOPE

The research involved systematic field and laboratory investigations over the entire known Natal Group depositional basin, from just north of Hlabisa in the north, to Hibberdene in the south, and on a reconnaissance basis as far south as the Mtamvuna River near Port Edward (Fig. 1.1).

1.2.1 GEOLOGICAL MAPPING

The author mapped selected portions within the basin, based on the position within the basin and the stratigraphic position of the rocks to be mapped. Aerial photograph interpretation played an important role in the understanding and recording of the geology in the field. The details were later transferred to 1:50 000 topographic maps. The mapping, which covered an area of 2477 km² (Table 1.1) was presented in internal reports of the Geological Survey of South Africa (Marshall 1987; 1988; 1991a; 1991b; 1991c). Selected portions are presented in Appendix 2 (Figs. App-2.1 and App-2.2 - App-2.14;).

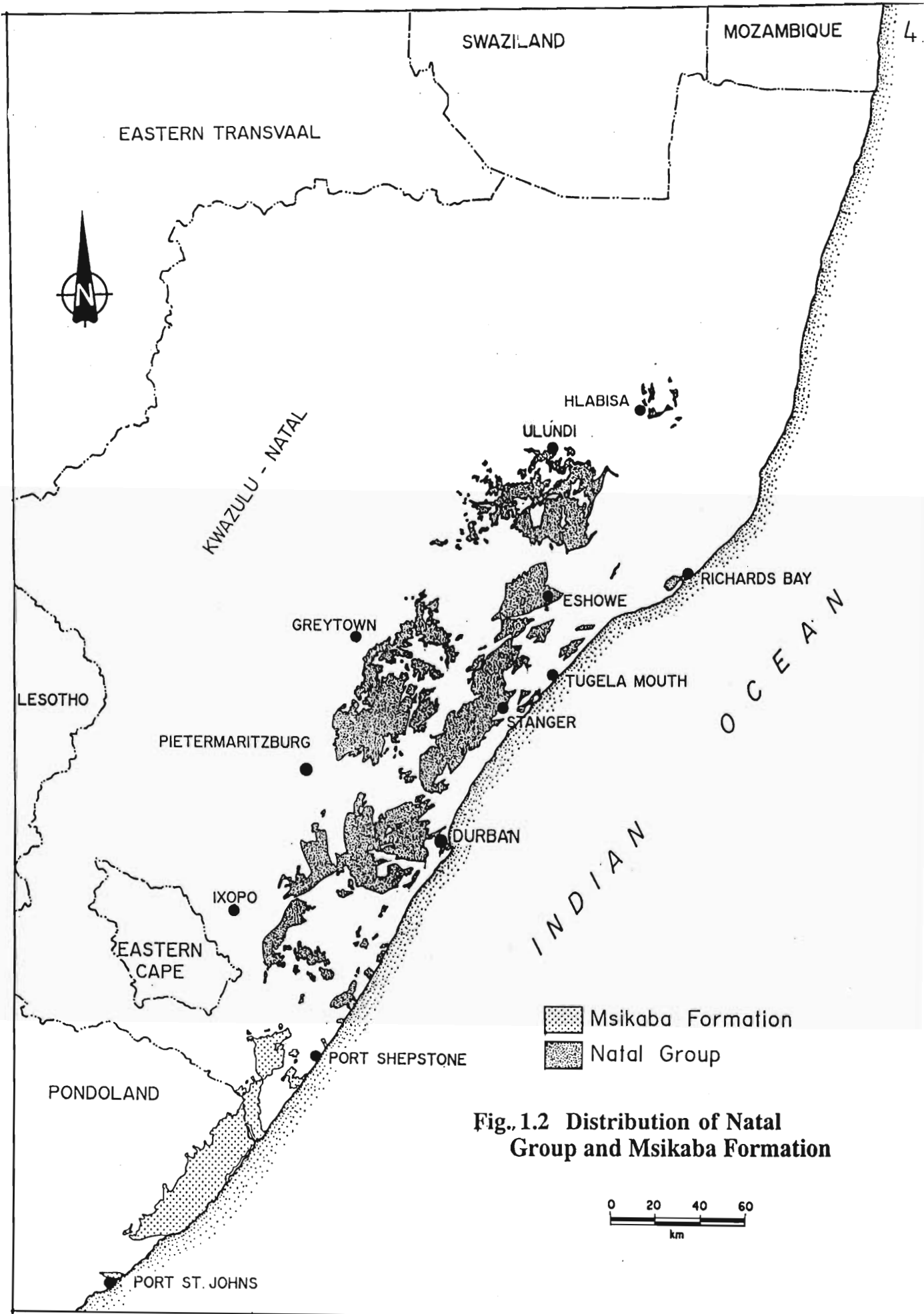


Fig. 1.2 Distribution of Natal Group and Msikaba Formation

Table 1.1: Summary of area mapped and sections measured

REGION	AREA MAPPED in km²	SECTIONS MEASURED	TOTAL THICKNESS in metres	YEAR
Inanda	700	39	2573	1986
Stanger-Eshowe	320	29	2137	1987
Melmoth	223	20	803	1988
Kranskop	934	38	1922	1989
S. Natal	300	31	1717	1990

1.2.2 VERTICAL SECTIONS

Vertical stratigraphic sections were measured in all of the units identified (Table 1.1; App-1.2; Fig. App-1.1). The sections were measured using an Abney level and a 1,5 m staff. Data were later transferred to log sheets devised and recommended by Johnson (1987; 1992). The measured vertical sections were presented in internal reports of the Geological Survey of South Africa (Marshall 1987; 1988; 1991a; 1991b; 1991c). Selected portions of these sections are presented in Appendix 1 (Figs. App-1.3 to App-1.27; Table App-1.2).

1.2.3 SAMPLING PROGRAMME

Some 600 samples were taken throughout the basin for petrographic study. The following samples for specialised study were also taken: Two samples of mudstone and sandstone, N1 and N2, were sent to FM Consultants at Oxford, Britain for K-Ar and $^{40}\text{Ar}/^{39}\text{Ar}$ age-dating. A selection of pebbles and cobbles was tested for compressive strength by the Geological Survey laboratory in Silverton. Sixteen samples, totalling 1708 individual clasts from the Ulundi and Tulini Members were taken for shape parameter determinations. The three major diametrical axes were measured, using a micrometer. The use of computer spread-sheet software aided the treatment of the clast shape data, and a programme by Cole and Basson (1986) was used for rotation of tilted-bed data and the statistical treatment of palaeocurrent measurements.

1.3 PREVIOUS WORK

1.3.1 STRATIGRAPHY

The first recorded reference to the rocks now known as the Natal Group was by Sutherland (1867), who called them the Palaeozoic Sandstone Formation. Other names applied to this succession were Palaeozoic Sandstone (Anderson, 1901), Table Mountain Sandstone (Anderson, 1904), Clairwood Sandstone (Schwarz, 1917), and Table Mountain Series (Krige, 1933). Various workers (Sutherland, 1868; Anderson, 1904; du Toit, 1920, 1931, 1946, 1954; Krige, 1933; Gevers, 1963; Hobday and Mathew, 1974; Visser, 1974; Kingsley, 1975; Hobday and von Brunn 1979; SACS, 1980; and Roberts, 1981, 1990;) have correlated the early Palaeozoic sandstones in Pondoland with those in KwaZulu-Natal (Fig. 1.2), but Schwarz (1917) firmly asserted that these same rocks were very different from the Table Mountain Sandstones of the then Cape Province, which included Transkei and Pondoland. This topic will be addressed Chapter 2 (stratigraphy).

Van Stratén (1953) was the first to attempt a stratigraphic subdivision of these rocks, followed by Rhodes and Leith (1967), Visser (1974), Kingsley (1975), and Roberts (1981). SACS (1980) synthesised the work of the previous workers, and produced an overall stratigraphy for the Natal Group.

Hardie (1958), Du Toit (1931) and Rhodes and Leith (1967) discussed the derivation of the fine and coarse sediments laid down to form the Natal Group.

1.3.2 THICKNESS

The thickness of the Natal Group has also attracted some attention, and has been variously recorded, as shown in Table 1.2 .

Table 1.2 Previously-recorded thicknesses of the Natal Group

AUTHOR	THICKNESS (m)	LOCALITY
Sutherland, 1868	120-150 300	KwaZulu-Natal Pondoland
Anderson, 1904	330 1	East of Melmoth North of Hlabisa
du Toit, 1931	450-600	Umhlatuzi Trough
Krige, 1933	450-600	Near Durban
Kent, 1938	426	North of Durban
du Toit, 1954	430 1200	Near Port Edward Eastern Pondoland
Gevers, 1963	150	Lilani Hot Springs
King and Maud, 1964	400	Near Durban
Rhodes & Leith, 1967	460	North of Durban
Kingsley, 1975	330	South of Durban
Roberts, 1981	500-600	Near Durban

The relative thicknesses of the subdivisions are represented in Fig. 2.1.

1.3.3 PALAEOLOGY

Had the Natal Group contained diagnostic fossils, the stratigraphy and correlation with other units would have been facilitated much earlier. Sutherland (1868) stated that the rocks now known as the Natal Group are barren of any fossils, but Griesbach (1871), while

recognising the lithological similarity of the rocks in KwaZulu-Natal and Pondoland to the Table Mountain Sandstone of the Cape Colony, also recorded the presence of some bivalves and a *Patella* in a thin shale band within the Natal Group near Kranskop. Anderson (1901) reported failure in attempts to locate this fossiliferous shale band, and thus confirmed the complete lack of fossils in the Natal Group. He was consequently unable to estimate the age of these rocks. Rilett (1969) identified the locality, but failed to find any fossil remains. He reasoned that the presence of a *Patella*, a degenerate rather than a primitive gastropod, would imply a late Devonian age, and was therefore highly unlikely at the reported discovery site.

Lock (1973) discovered and identified protolycopods in what has hitherto been generally regarded as Natal Group sandstone 5 km west of Port St. Johns. Because lycopsids were rare in early Devonian times, and became abundant only in the late Devonian, he suggested that it is highly unlikely that any rock containing lycopsids (the so-called Natal Group at Port St. Johns included) could be correlated with the pre-Devonian Table Mountain Group of the Eastern and Western Cape Provinces. He therefore suggested that the Natal Group rocks in KwaZulu-Natal and Pondoland are the equivalent of the Witteberg Group of the Eastern and Western Cape Provinces. Hobday and Mathew (1974) recorded the occurrence of the trace fossils *Scolicia* and *Planolites* in sandstones of the Cape Supergroup of Pondoland. This was taken as evidence of a shallow marine shelf environment of deposition for the rocks in Pondoland. It has since become evident that the rocks in the Transkei are not continuous or isochronous with their supposed equivalents in KwaZulu-Natal. This is discussed further in Chapters 2 (Stratigraphy) and 6 (Deposition). All further attempts to find fossils in the Natal Group have proved fruitless.

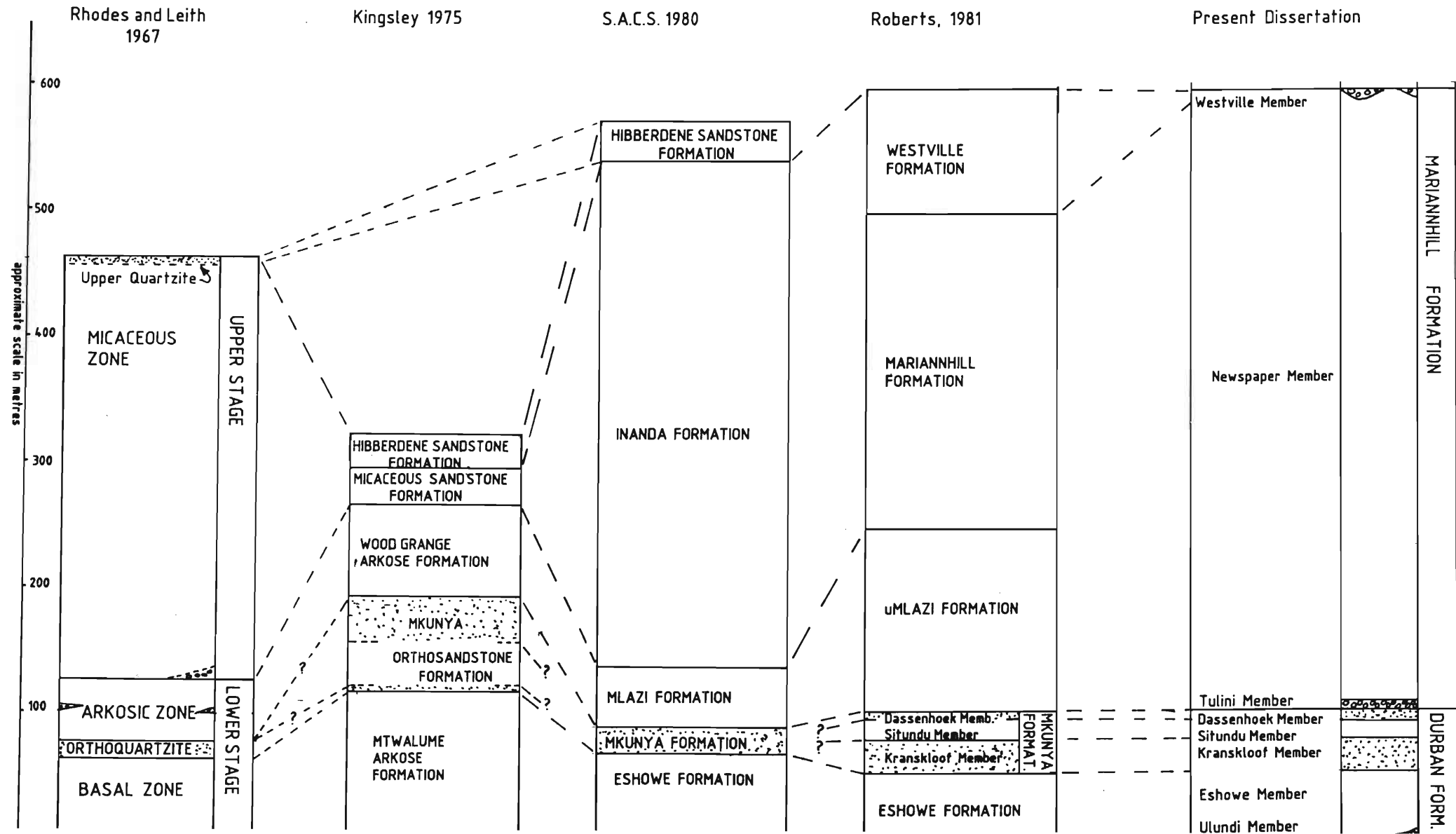
2. STRATIGRAPHY

2.1 EARLY STRATIGRAPHIC SUBDIVISIONS

The recognition of a persistent conglomerate zone by Kent (1938), the description of five distinguishable units including a "resistant quartzite (fall-marker)" band near Shongweni by Dodson (1951, p.6), and the identification of four distinct zones, including a "quartzite zone" near Umlazi by van Straten (1953, p.18), were the first attempts to subdivide the Natal Group. With the limited number of units present in the Natal Group, there can be little doubt that the names "resistant quartzite (fall-marker)" and "quartzite zone" refer to the same stratigraphic unit, as the respective authors place them second in succession, and some 50 m above the granitic basement. Added to this, the lithology and thickness of these two units agree in essence.

The author has attempted to relate the various stratigraphic subdivisions produced previously (Fig. 2.1), but the task has been made difficult by the lack of any clear commitment by previous authors to correlate their units with those of other authors. This situation came about largely because the various workers have investigated different areas at different times, and there are local variations in the development of the various stratigraphic units which had not been recognised previously, but which are now recorded in this dissertation. Disparities in thickness are not important at this level, as there is a considerable regional variation in the thicknesses of the various units.

Fig. 2.1 Stratigraphic comparisons



2.2 RHODES AND LEITH (1967)

Rhodes and Leith (1967) were the first to formally publish a full stratigraphic subdivision of the Natal Group (Fig. 2.1), with two stages, three zones, and the "Orthoquartzite Marker", this last being the "resistant quartzite (fall-marker)" identified by Dodson (1951) and the "quartzite zone" of van Straten (1953). The Upper Quartzite of Rhodes and Leith presents a problem in that it is not represented in any of their measured sections, and the author could not locate such a unit anywhere in the basin.

2.3 KINGSLEY (1975)

Kingsley (1975) recognised the lithological disparity between the Natal Group in KwaZulu-Natal (Hibberdene facies) and its correlate in southern KwaZulu-Natal and Pondoland (Margate facies), and published a stratigraphic subdivision of each.

Kingsley's (1975) Mtwalume Arkose Formation and Rhodes and Leith's (1967) Basal Zone are clearly the same unit, as they both lie at the base of the sequence, in direct contact with the Precambrian basement, and are overlain by quartzitic sandstone. In Kingsley's (1975) Mkunya Orthosandstone Formation there are two quartzitic units, the lower of which is presumably the equivalent of Rhodes and Leith's (1967) Orthoquartzite Marker, the upper one being the equivalent of Rhodes and Leith's quartzitic and gritty sandstone lenses which they place some 30 m above their Orthoquartzite Marker. In both cases the two quartzitic sandstone units are separated by coarse, gritty, arkosic sandstones, which were not named.

From the above it should follow that Kingsley's (1975) Wood Grange Arkose Formation would seem to be the equivalent of the portion of the Arkosic Zone above the quartzitic and gritty sandstone lenses of Rhodes and Leith (1967), although Kingsley, in his Fig. 2, appears to correlate the Wood Grange Arkose Formation with the whole of the Arkosic Zone of Rhodes and Leith (1967). This is highly improbable, as shown by the author in the discussion on the Mariannahill Formation and the Tulini Member below. The Micaceous Sandstone Formation would be the unit named Micaceous Zone by Rhodes and Leith (1967).

The Hibberdene Sandstone Formation is taken by SACS (1980) to be the equivalent of the Upper Quartzite of Rhodes and Leith (1967), but the existence of this Upper Quartzite is in question, as discussed in paragraph 3.2 above. Further, the writer does not agree with Kingsley's (1975) placing of this stratigraphic unit in the Hibberdene facies, as Kingsley himself stated that the presence of this unit at Hibberdene is due to a northward transgression of the sea in which the Margate facies was deposited. It should therefore, lithostratigraphically, be placed in the Margate facies and not in the Hibberdene facies.

2.4 THE SOUTH AFRICAN COMMITTEE FOR STRATIGRAPHY (SACS), 1980

Lock (1973) discovered Devonian Lycopoid fossils in what had hitherto been regarded as Ordovician/Silurian Table Mountain Series rocks near Port St. Johns in Pondoland. The Working Group for the Cape System then suggested to the Central Committee of SACS, that these rocks in Pondoland and KwaZulu Natal be called "The Natal Group", to distinguish them from the older rocks of the western Cape Province. This was recorded in the minutes of the 10th meeting of SACS Central Committee, September, 1975.

SACS (1980), in an attempt to produce a formal and standardised stratigraphy for the Natal Group, referred to the work of Rhodes and Leith (1967) and Kingsley (1975), and compiled a stratigraphic column accordingly. SACS (1980) also called upon the personal experience of P.E. Matthews and D.L. Roberts in naming the units already identified, and such additional units as were deemed necessary.

The Eshowe Formation is clearly the same unit as the Mtwalume Arkose Formation of Kingsley (1975). The name was suggested by P.E. Matthews in a personal communication. The succeeding Mkunya Formation is the same as Kingsley's (1975) Mkunya Orthosandstone Formation, although SACS (1980) gives no indication of any further subdivision of their Mkunya Formation, in spite of the fact that this is clear (but unnamed) from the work of Rhodes and Leith (1967) and Kingsley (1975). In this context, Gevers (1963) noted that there are two stratigraphically specified quartzitic bands, separated by softer sedimentary rocks with a less-pronounced outcrop expression, in the Lilani hot springs area southeast of Greytown.

The Mlazi and Inanda Formations are, respectively, the equivalents of the Wood Grange Arkose Formation and the Micaceous Sandstone Formation of Kingsley (1975).

The Hibberdene Sandstone Formation was adopted directly from Kingsley (1975) and has been discussed under that heading.

The name for the Ulundi Member was suggested by P.E. Matthews in a personal communication to SACS, and refers to the coarse conglomerate at the base of the Natal

Group in the Ulundi area.

The rocks in Pondoland, which were correlated with the Natal Group, but were considered (by SACS, 1980) to be stratigraphically indivisible, were named the Msikaba Formation. This was also proposed by P.E. Matthews in a personal communication to SACS.

2.5 ROBERTS, 1981.

The Eshowe Formation was retained from SACS (1980), as was the Mkunya Formation, although Roberts subdivided this unit into the Kranskloof (silicified quartz arenite), Situndu (arkosic, gritty sandstone) and Dassenhoek (silicified quartz arenite) Members, thus formalising the situation described by Kingsley (1975), and hinted at by Gevers (1963).

The name "uMlazi Formation" was suggested to SACS (1980) by Roberts in a personal communication.

Roberts (1981) introduced the Mariannahill Formation, which is largely the same as the Inanda Formation of SACS (1980).

He also recognised a sporadically-developed conglomeratic unit above the Mariannahill Formation, which he named the Westville Formation.

2.6 PRESENT WORK

There were several problems in the existing stratigraphic subdivisions of the Natal Group, and the present study was initiated largely as an attempt to rectify this. At the commencement of the present study there was no overall synthesis of the stratigraphy of the Natal Group. Rhodes and Leith (1967) had discussed the area north of Durban and Kingsley (1975) attended to the area south of Durban. SACS (1980) presented a compilation of previous work. Roberts (1981) produced a workable stratigraphy for the Natal Group in the Durban area. The current investigation has revealed that none of the existing stratigraphic subdivisions was workable for the whole of the Natal Group occurrence, and the author has attempted to rectify this unsatisfactory situation by proposing a workable stratigraphic subdivision of the Natal Group as a whole. This is summarised in Table 2.1.

Table 2.1 Proposed stratigraphic subdivision of the Natal Group

FORMATION	MEMBER	DOMINANT LITHOLOGY
MARIANNHILL	Westville	matrix-supported conglomerate
	Newspaper	arkosic sandstone
	Tulini	small-pebble conglomerate
DURBAN	Dassenhoek	silicified quartz-arenite
	Situndu	coarse arkosic sandstone
	Kranskloof	silicified quartz-arenite
	Eshowe	arkosic sandstone and shale
	Ulundi	coarse clast-supported conglomerate

2.6.1 DURBAN FORMATION

The name **Durban Formation** was chosen by the author to encompass the five lower members of the Natal Group, as it is well developed in the Durban area. It commences with a basal conglomerate, passes up into arkosic sandstones, and ends with quartz-arenite, succeeded by the basal conglomerate of the overlying Mariannhill Formation, it was seen to represent a sedimentary cycle.

2.6.1.1 The Ulundi Member: This member was identified (SACS, 1980) as a conglomeratic unit at the base of the Natal Group in the north of the basin. Mapping within the basin confirmed this, with the addition of several minor occurrences in the south of the basin (Fig. 3.15; and geological maps Fig. App-2.3, App-2.5; App-2.6, App-2.10, App-2.11; App-2.13). The type area is taken as the north bank of the White Mfolozi River south of Ulundi (Fig. 1.1).

2.6.1.2 The Eshowe Member: The name Eshowe is retained in this unit, which is that portion of the former (SACS, 1980) Eshowe Formation which occurs between either the Kranskloof Member or Mariannhill Formation above, and either the Ulundi Member or the granitic basement below. The reason for this change of nomenclature of SACS and Roberts is as follows. The Kranskloof Member lenses out northwards in the vicinity of Eshowe (Fig. 1.1). Rhodes and Leith (1967) did not recognise it in the vicinity of Eshowe, but the present investigation revealed that it does occur as far north as the Mhlatuze River (Figs. 1.1; App-2.3). North of the Mhlatuze River, the Situndu Member rests directly on rocks of the Eshowe Member (Fig. App-2.15). The small lithological differences between the Eshowe and Situndu Members (Roberts, 1981) are not sufficient to make them separately

mappable in the absence of an intervening marker, as equally significant local variations occur within these members. The Eshowe and Situndu Members therefore merge into one unit, a clearly untenable situation if the two units do not belong to the same formation. The author has thus retained the name "Eshowe Member" for the portion of the succession which includes the mutually indistinguishable Eshowe and Situndu Members. The same procedure was followed by the compilers of the 1:250 000 Geological Survey map of area 3220 in the W. Cape (Sutherland). Here the Skoorsteen Formation lenses out, and the overlying Koedoesberg Formation merges with the underlying Tierberg Formation, and the name Tierberg Formation is retained.

The main reason for the separate existence of the Mkunya Formation (SACS, 1980; Roberts, 1981), as distinct from the preceding Eshowe Formation and the succeeding Mariannhill Formation above, is the presence of the two quartz-arenite units (Kranskloof and Dassenhoek Members). As discussed in more detail later in this and Chapter 6, these two units were thought to be littoral deposits laid down during a regression following a marine transgression from the south. They are separated by the coarse, arkosic sandstones of the Situndu Member which resulted from a temporary progradational event (Rhodes and Leith, 1967; Visser, 1974; Hobday and von Brunn, 1979; Roberts, 1981; Roberts, 1990). The presence of quartz arenites does not necessarily imply a marine environment of deposition (Kingsley, 1975; Chandler, 1988; Aspler *et al.* 1994). The non-marine origin of the Kranskloof and Dassenhoek Members is discussed in Chapter 6. Further, it has been shown (Marshall, 1991; Thomas *et al.* 1992) that the Natal Group rocks are much older than the marine sedimentary rocks of the Devonian Msikaba Formation of Pondoland (Lock, 1973) which were formerly believed to be part of the Table Mountain Group. The Natal Group and the Msikaba Formation are no longer correlated with each other, and it

is not justified to retain a separate formation to accommodate the two quartz arenite members which were hitherto thought to have been of marine origin.

The Eshowe and Mkunya Formations (SACS, 1980; Roberts, 1981) have been discontinued whereas the Ulundi, Eshowe, Kranskloof, Situndu and Dassenhoek Members have been included in the new Durban Formation.

2.6.1.3 Kranskloof Member This name was introduced by Roberts (1981), and is retained to identify the lower of the two quartz-arenite units in the Durban Formation. The type area is the Kranskloof Nature Reserve in Kloof, northwest of Durban. Du Toit and Leith (1974) correlated the quartzitic sandstone intersected in borehole JC-1 30 km off the KwaZulu-Natal coast near Stanger, with the Upper Quartzite of Rhodes and Leith (1967). They also correlated the overlying greenish grey diamictite, with which the quartzite has a gradational contact, with the "Dwyka Tillite of the Southern Cape Province" (p. 249, 250). The author has not seen the borehole core, but feels that the quartzite could be the Kranskloof Member, and the diamictite could be the Tulini Member. Doubts as to the existence of the Upper Quartzite are discussed under 3.2 above, and the gradational contact with the overlying "diamictite" seems unlikely if the diamictite belongs to the Dwyka Group, considering the difference in age. The Natal Group is now known to be 490 Ma, (Thomas *et al.* 1992) and the age of the base of the Dwyka Group indicated as approximately 290 Ma (Visser, 1990).

2.6.1.4 Situndu Member The name Situndu Member was introduced by Roberts (1981) to identify the coarse arkosic argillites occurring between the Kranskloof and Dassenhoek

Members. The type area is to the southwest of Durban.

2.6.1.5 Dassenhoek Member Roberts (1981) proposed the name Dassenhoek Member for the upper of the two quartz-arenite units of what is now the Durban Formation. The type area is to the southwest of Durban.

2.6.2 MARIANHILL FORMATION

This Formation, named by Roberts (1981), has been extended by the present author to include Roberts' uMlazi and Westville Formations, as well as the new Tulini Member.

2.6.2.1 The Tulini Member The Tulini Member, named by the author after the Tulini area east of Greytown, is probably the same as a) the persistent conglomeratic zone mentioned by Kent (1938), b) the thin pebble beds of Krige (1933), c) the monomict small-pebble conglomerates of Gevers (1963) and d) the pebbly grits recorded by Rhodes and Leith (1967) at the base of their Micaceous Zone. It is the lowest unit of the Mariannahill Formation and the basal contact is paraconformable. In the north it overlies the Eshowe Member directly, and southwards it progressively oversteps onto the Kranskloof, Situndu and Dassenhoek Members of the Durban Formation. It forms a useful marker (Fig. App-2.15).

2.6.2.2 The Newspaper Member The present study revealed that the uMlazi Formation (SACS, 1980; Roberts, 1981) is not a mappable unit over the whole basin, and although the arenaceous and argillaceous rocks above the Dassenhoek Member might be locally

slightly more micaceous than the rocks higher up in the succession, there is no mappable horizon at which the boundary can be taken, and it is not possible to differentiate, on a regional scale, any unit which is more micaceous than any other. The author has therefore included these rocks as an integral part of the Newspaper Member, and has not considered perpetuating the name uMlazi.

Because the Mariannahill Formation is subdivided into three distinct units, it is necessary to name at least two of these units, and to accord them member status. The naming of the two conglomeratic members (Tulini and Westville) has met with no opposition, but there appears to be some doubt as to the necessity of formally naming the central, arkosic sequence of arenites which lies between the two conglomeratic units. If this central unit is not formally named, then reference to it would entail using one of the following unsatisfactory informal names: a) the rest of the Mariannahill Formation, b) the balance of the Mariannahill Formation, c) the major portion of the Mariannahill Formation or d) the non-conglomeratic portion of the Mariannahill Formation.

None of these terms is satisfactory. Alternatives a) and b) imply minor status to an ill-defined succession of rocks which, in fact, constitutes between 90 and 100% of the Mariannahill Formation. Alternative c) indicates anything more than 50% of the formation, and would not necessarily exclude either of the conglomeratic members. Also, by using c), there is no necessary implication of a continuous succession, but merely sufficient beds to constitute more than 50% of the formation. The use of d) would also be ambiguous, as it could include the non-conglomeratic beds within the Tulini and Westville Members. The author's initial choice of Ngcongcongga Member, after the locality in which the unit is

very well developed, was discarded because of anticipated difficulty in spelling and pronunciation.

The author has therefore decided to name the portion in question the "Newspaper Member" after the area (Fig. 1.1) in the Umvoti Location, northeast of Appelsbosch Mission, and near where the unit is particularly well developed (Ngcongcongga). The distribution is shown in Fig. App-4.7). The area between Appelsbosch and Newspaper is the type area.

2.6.2.3 The Westville Member The Westville Formation, identified and named by Roberts (1981) is a sporadically-developed conglomeratic unit occurring at, or near the top of the Natal Group stratigraphic pile. The writer contends that it is too sparsely developed, to be a formation, and is thus given member status. The type area is Westville, to the northwest of Durban (Fig. 1.1).

2.6.3 GENERAL CONSIDERATIONS

In their generalised section of their Table Mountain Series in the northern coastal regions of KwaZulu-Natal, Rhodes and Leith (1967, p.17) placed the "pebbly grit" some 25 m above the quartzitic lenses which are taken to be what is now known as the Dassenhoek Member. However, none of their sections I to VII (Rhodes and Leith, 1967, Fig.3, facing p.20) display either the pebbly grits or quartzitic sandstone lenses. Their Section V is to the north of the northern limit of the Dassenhoek Member, and their Section III is to the south of the southern limit of the Tulini Member (See Chapter 3, Dassenhoek and Tulini Members). distribution of Tulini Member). The Tulini Member does not rest on rocks any

younger than the Dassenhock Member (Marshall, 1988; 1991a; 1991b). Therefore, the 25 m of Arkosic Zone which Rhodes and Leith (1967) place between the quartzitic lenses below, and the pebbly grit above, does not exist, and Rhodes and Leith (1967) should have placed the pebbly grits immediately above the quartzitic lenses. It is apparent that these inconsistencies are the result of insufficient data on which to base their stratigraphic column. The upper portion of the Arkosic Zone thus falls away, and is not to be correlated with the Arkose Formation as suggested in Kingsley's (1975) Figure 2.

2.6.3.1 Correlation of Early to Middle Palaeozoic rocks in Pondoland with those in

KwaZulu-Natal: Previously, the Natal Group, commonly referred to as the Table Mountain Series, was believed by most workers (du Toit, 1946, 1954; Rhodes and Leith, 1967; Hobday and Mathew, 1974; Visser, 1974; Kingsley, 1975; Hobday and von Brunn, 1979; Roberts, 1981; and Roberts, 1990) to extend as far south as Port St. Johns (Geological Survey of South Africa, 1:1 000 000 Geological map of South Africa, 1984). Schwarz (1917), however, recognised two differing lithologies to the north and south, respectively, of Port Shepstone. The rocks to the north were described as reddish, arkosic sandstones, while the rocks to the south consist of clean, pale grey quartz arenites. Schwarz proposed that the rocks to the north of Port Shepstone are much older than those to the south, and postulated that it was inconceivable that the Table Mountain sandstone of Pondoland and southern KwaZulu-Natal could change to what he named the Clairwood Sandstone of KwaZulu-Natal over a distance of only 8 km. Du Toit (1920), possibly referring to Schwarz (1917) drew attention to the fact that the correlation of the Table Mountain sandstones in KwaZulu-Natal with that in the Cape Province, had been questioned. Du Toit reiterated categorically that the two are lithologically identical,

including the presence of a brick-red shale at the base. Du Toit (1920) was probably comparing the southern assemblage of Pondoland (and not the northern assemblage of KwaZulu-Natal) with the Table Mountain Sandstone of the Western Cape Province, as he recognised the differences between the lithologies of the rocks to the north and south, respectively, of Port Shepstone. Du Toit (1954) stated, without further reference, that Schwarz's (1917) lithological and chronological separation of the rocks to the north and south, respectively, of Port Shepstone, was controverted without difficulty. So that there is no confusion, the present author, in referring to the lithologies in KwaZulu-Natal and Pondoland, uses the word "assemblage" rather than "Facies", which has been used by other authors. To substantiate the equivalence of these two assemblages, du Toit reported that the white quartz arenites of the southern assemblage pass laterally northwards near Highflats into red feldspathic sandstones of the northern assemblage, possibly inferring a lateral facies change from marine to terrestrial deposits.

Other workers have also recognised this lithological disparity, as in Table 2.2 below.

Table 2.2 Historical recognition of lithological disparities

	NORTHERN ASSEMBLAGE	SOUTHERN ASSEMBLAGE
Schwarz (1917)	Clairwood Sandstone	Table Mountain Sandstone
du Toit (1954)	red feldspathic sandstones (informal)	white sandstone (informal)
Hardie (1958)	Red Facies	Grey Facies
Visser (1974)	Natal Facies	Pondoland Facies
Kingsley (1975)	Hibberdene facies	Margate facies

Hardie (1958), Visser (1974) and Kingsley (1975) introduced the concept of two facies, to the north and south, respectively, of Hibberdene on the KwaZulu-Natal South Coast (Table

2.2) to accommodate the lithological disparity between the two assemblages which were, at that time, regarded as mutual equivalents.

Scant cognisance of the differences between the northern and southern assemblages (Table 2.3) was taken in correlating the northern and southern assemblages.

Table 2.3 Lithological and interpretative differences of the northern and southern assemblages.

NORTHERN ASSEMBLAGE	SOUTHERN ASSEMBLAGE
Unfossiliferous	Fossiliferous (Lock, 1973; Hobday and Mathew, 1974; Hobday <i>et al.</i> 1971; Kingsley, 1975)
Ordovician 490 Ma ($^{40}\text{Ar}/^{39}\text{Ar}$, Thomas <i>et al.</i> 1992)	Devonian, 350 Ma, (Lock, 1973)
Braided fluvial	Shallow marine
Immature	Mature
Arkosic sandstone	Clean quartz arenite
Sandstone and shale interbedded	Quartz arenites predominant
Colour is red	Colour is pale grey

It is important to note that, on the beach at Wood Grange, at the correct stratigraphic position within the northern assemblage red beds, there are two greyish-red quartz arenites - the Kranskloof and Dassenhoek Members respectively - which are stratigraphically far below the pale grey quartz arenites which Kingsley (1975) called the "Hibberdene Sandstone Formation".

The author has thus decided to restrict the term "Natal Group" to the red-bed sequence north of Hibberdene, and to call the quartz-arenite sequence which extends southwards from

Port Shepstone into Pondoland, the "Msikaba Formation". This name was suggested by P.E. Matthews, from the Msikaba River northeast of Port St. Johns (SACS, 1980). The Msikaba Formation is not divisible into distinct mappable lithostratigraphic units (SACS, 1980), as confirmed during the current study (Fig. App-1.27 - measured vertical section at Port Edward).

3. DESCRIPTION OF THE NATAL GROUP UNITS

The Natal Group consists of a monotonous reddish-grey succession of sandstones with subordinate siltstones, shales and conglomerates. It overlies the Precambrian granitic and supracrustal rocks of the basement unconformably, and is disconformably overlain by the rocks of the Dwyka Group (Marshall, 1987, 1988, 1991a, 1991b and 1991c).

Mutual relationships of the various stratigraphic units of the Natal Group, comprising the Durban and Mariannhill Formations, are shown in selected geological maps (Figs. App-2.2 - App-2.14), and measured sections (Figs. App-1.3 - App-1.27) produced during this study. The key to the vertical sections is in Fig. App-1.2. The various stratigraphic units represented in the sections presented in this dissertation, are shown in Table App-1.2. Particle sizes are based on the Wentworth particle size classification (Krumbein and Sloss, 1963). All rock colours referred to in this chapter are according to the Munsell scale (Goddard *et al.* 1948).

The sandstone classification used in this dissertation is that proposed by Mc Bride (1963). The composition plots shown on the Mc Bride (1963) diagrams for each unit are derived from the determined composition statistics in Table App-3.2. The cement is included as a component of the rocks investigated, but in plotting the Mc Bride ternary diagrams, the percentage of quartz and chert, feldspar and lithics have been normalised after removal of the cement, as the cement content is not a factor in sandstone classification.

3.1 DURBAN FORMATION

The Durban Formation is the older of the two formations proposed for the Natal Group, and occurs throughout the Natal Group depositional basin. The name was proposed by the author, as the unit is well developed in the vicinity of Durban. This formation is capped by resistant lithologies and is consequently more conspicuous than the younger Mariannahill Formation. The Durban Formation begins with a basal conglomerate which is followed by a succession of arkosic sandstones and shale, and ends with two quartz-arenite units separated by arkosic sandstone.

3.1.1 ULUNDI MEMBER

3.1.1.1 General The name Ulundi was proposed by Matthews (in SACS, 1980), who also identified the type area as the north bank of the White Mfolozi River, 1,5 km downstream from the bridge over the river on the old road between Melmoth and Ulundi. This member is distinguished by boulder- to pebble-conglomerates and subordinate interbedded sandstones and shales.

Occurrence of the Ulundi Member is limited to lenticular bodies in the northern and northwestern portions of the Natal Group depositional basin with some minor occurrences in the southwest (Figs. 3.15; App-2.15). This, the oldest unit in the Natal Group, rests unconformably on the Precambrian basement rocks (Fig. 3.1) and is usually overlain by rocks of the Eshowe Member except in certain localities near the western margin of the basin where it is overlain by rocks of the Dwyka Group (Figs. 3.2, App-2.15).



Fig. 3.1 Ulundi Member conglomerate resting on ferruginous Pongola Supergroup argillite, west of Ulundi.



Fig. 3.2 Stratified Ulundi Member overlying basement and overlain by Dwyka Group, south of Babanango. Contacts shown by arrows.

3.1.1.2 Thickness: The large range in the thickness of the Ulundi Member (from 1 to 59 m), as summarised in Table 3.1, is a reflection of both bedrock topography, and the deposition within intermontane valleys and on associated alluvial fans. The first column, Area, refers to the areas of study as outlined in Figure 1.1. The maximum thickness was measured in the type area (Stratigraphic section, Fig. App-1.8).

Table 3.1 Thickness of Ulundi Member (metres)

AREA	NUMBER OF SECTIONS MEASURED	MEAN THICKNESS	MINIMUM THICKNESS	MAXIMUM THICKNESS
MELMOTH	7	15,7	1,5	59,4
ESHOWE	2	1,25	1,0	1,5
KRANSKOP	4	29,6	2,0	47,0
DURBAN	0	--	--	--
SOUTHERN K'-NATAL	4	16,7	2,9	31,5
OVERALL	17	17,6	1,0	59,4

3.1.1.2 Lithology

The Ulundi Member consists of greyish red, usually matrix-poor, clast-supported, conglomerate with minor lenticular beds of sub-arkosic sandstone and shale.

Conglomerate: The conglomerates are monomict, consisting of greyish red to dusky red, very well-rounded quartzite clasts (Fig. 3.3) and minor jasper which is less well-rounded. The matrix comprises poorly-sorted, clayey sandstone which is very ferruginous. The largest clast observed has a long axis diameter of 0,5 m, but larger clasts have been reported (du Toit, 1931: 1 m; Matthews, 1961: 2 m; Hobday and von Brunn, 1979: 2 m).

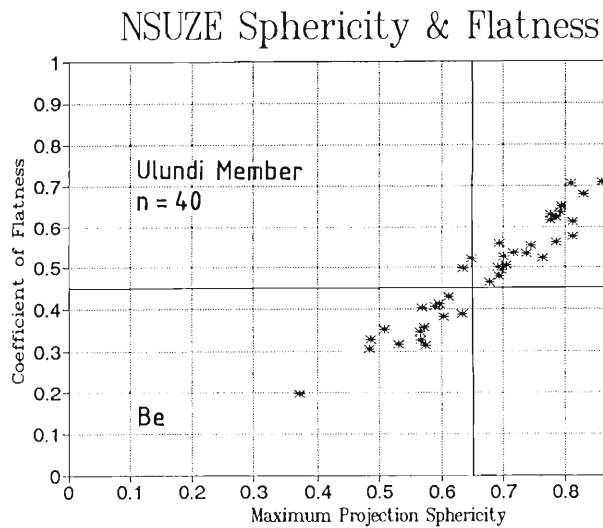
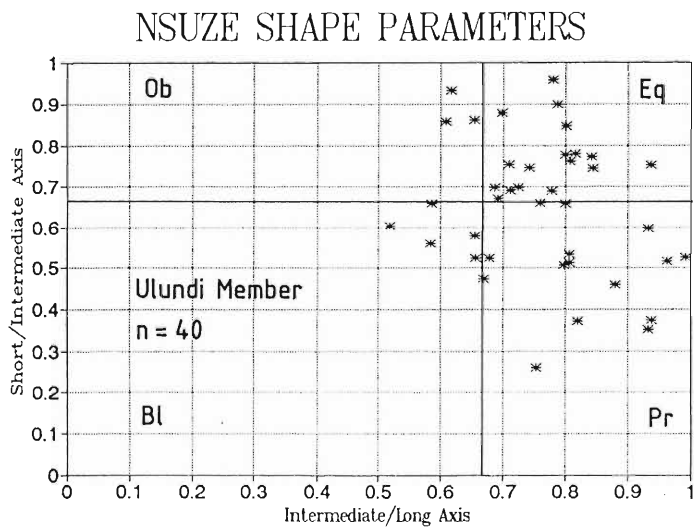


Fig. 3.3 Imbricated, well-rounded clasts in monomict Ulundi Member conglomerate, south of Ulundi.

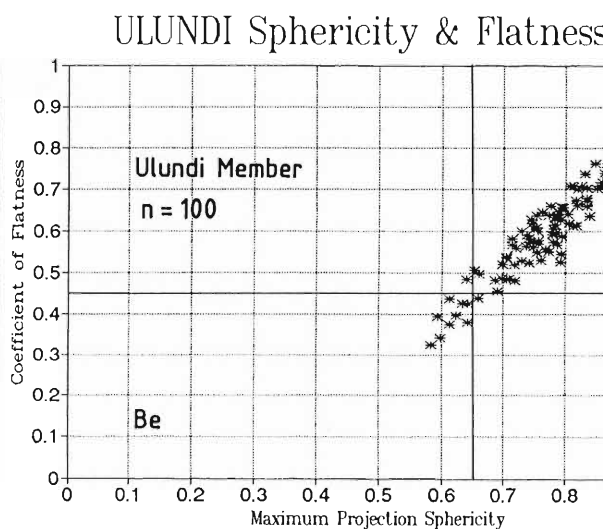
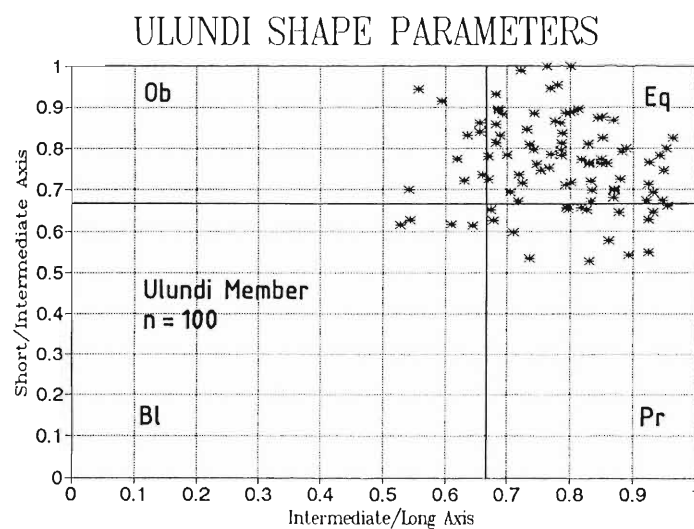
An estimated mean long axis diameter, for the type area, is 150 mm. Normally, in the Ulundi Member, there is no marked relationship between clast size and the vertical position within the unit, but at Nsuze (Marshall, 1991c) there is a general grading from a mean long axis diameter at the base of 0,26 m, through 0,78 m some 15 m above the base, to 0,1 m at the top - some 42 m above the base. The maximum clast size is 0,605 m at the base and 0,41 m at the top.

The clasts are predominantly equant with a high degree of sphericity. Some scatter into the prolate, bladed and oblate fields (Zingg, 1935; Boggs, 1987; Barrett, 1980) (Fig. 3.4) occurs. Scatter in the sample taken from the Nsuze area is more pronounced than in those taken from the type area at Ulundi and from Dolwana (Fig. 1.1). The clasts of the Ulundi Member conglomerate exhibit pressure solution hollows and fracturing at most occurrences.

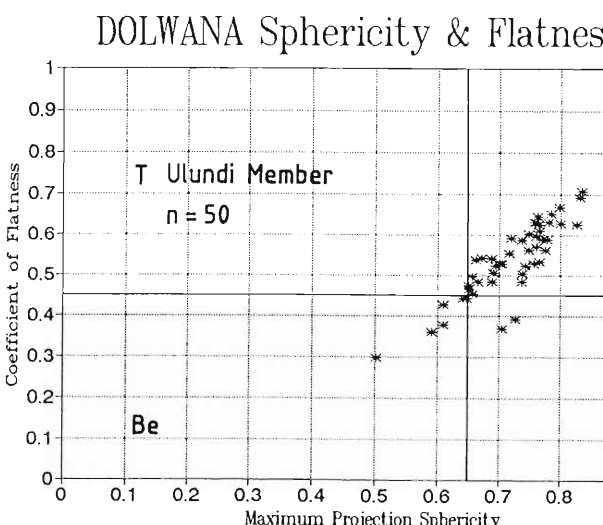
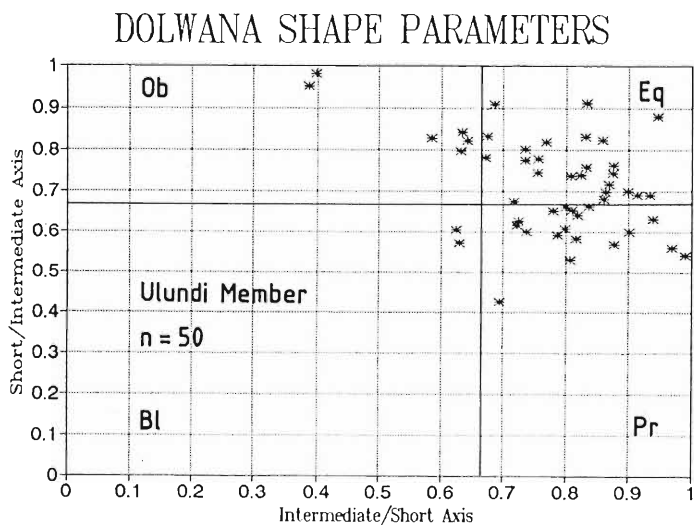
Locally, deposits with flat-lying angular clasts are developed. In Fig. 3.5 the clasts are well rounded, but are clearly aligned horizontally. The conglomerate is clast supported, but the matrix is not sparse. It would thus seem to be a cohesive debris-flow, as described by Lowe (1982), with a clast-supported fabric and a variable, but generally small, proportion of fine-grained matrix. The outcrop illustrated in Fig. 3.6 has a similar deposit at the base, immediately overlying the basement, with a matrix-supported conglomerate containing angular, horizontally-aligned clasts, overlying it. This is also seen to be a debris-flow deposit. It would seem that the order of deposition seen in Fig. 3.6 can be reversed, as seen in Fig. 3.7, indicating that these two types of conglomerate occur as pulses, and the nature depends on the type of clast and amount of sand-clay slurry available. Other deposits with unsorted, unoriented, very angular clasts also occur (Fig. 3.8). These are also



a) Nsuze River valley (sampling locality P)



b) Ulundi (sampling locality O)



c) Dolwana (sampling locality N)

Fig. 3.4 Shape Parameters and Flatness vs Sphericity, ULUNDI MEMBER.

Ob = oblate; Eq = equant; Bl = bladed; Pr = prolate Fl = fluvial; Be = beach; n = number of clasts measured
--



Fig. 3.5 Clast-supported Ulundi Member conglomerate with flat-lying clasts, transported by hyperconcentrated flood flow, south of Ulundi, south bank of White Mfolozi River.



Fig. 3.6 Base of Ulundi Member. Note debris-flow (see Collinson and Thompson, 1982, p. 110) with flat lying, angular clasts, and underlying clast-supported to matrix-supported conglomerate with flat-lying clasts, south of Babanango.



Fig. 3.7 Base of Ulundi Member, southeast of Babanango showing angular, tabular clasts with horizontal orientation, overlain by conglomerate with typical rounded clasts and high matrix content.



Fig. 3.8 Ulundi Member conglomerate with angular clasts northeast of Nkandla.

interpreted as debris flow deposits. At the top of measured section in the type area (Fig. App-1.8), there are two atypical beds of conglomerate, each 1 m thick and lying in direct vertical juxtaposition. They are tabular, polymict and matrix-supported. The clasts are well rounded and consist of white quartz, grey and green quartzite and black chert. The clast-packing-density (Kahn, 1956) is 50%. The mean long axis diameter is 68 mm, and the maximum is 200 mm. The matrix is silicified, coarse-grained to very coarse-grained sub-arkosic sandstone which is pale red.

In comparison with the conglomerates of the Tulini Member, it is seen that the mean nominal diameter is much larger in the Ulundi conglomerates, and the oblate/prolate index is much smaller. The elongation, apart from the sample from Nsuze, is greater. Also, the sample from Nsuze shows lower sphericities and coefficients of flatness than samples from the Tulini Member.

At two localities, respectively at the base and near the top of the stratigraphic section measured in the type area (Fig. App-1.8), the azimuths of the longest horizontal axes of 402 clasts, as seen on the bedding surfaces, were measured and plotted as a rose diagram (Fig. 3.9). It is clear that there is no preferred orientation of the clasts at these positions, indicating a lack of pronounced imbrication. Reddering (pers. comm.)¹ has explained the shape of this diagram as follows: a) The largely equant clasts would not be expected to produce imbrication, as a short to intermediate axis ratio of less than 1/3 is required for clear imbrication to develop; and b) The maltese cross configuration of this rose diagram (Fig. 3.9) is typical of fluvial environments, where the ellipsoidal clasts roll and are aligned

¹ J.S.V. Reddering, Council For Geoscience, Port Elizabeth

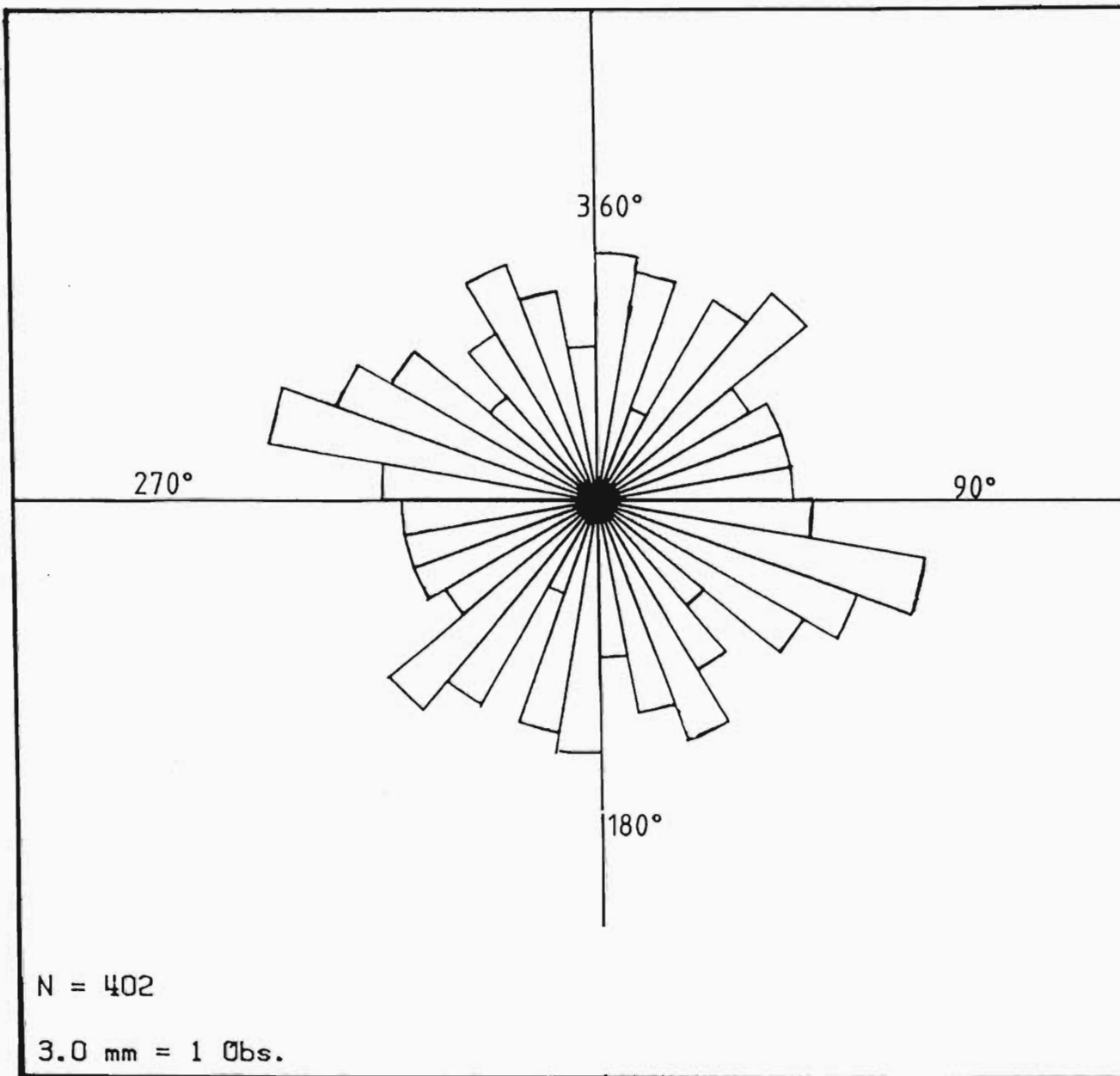


Fig. 3.9 Orientation of Ulundi Member clasts.

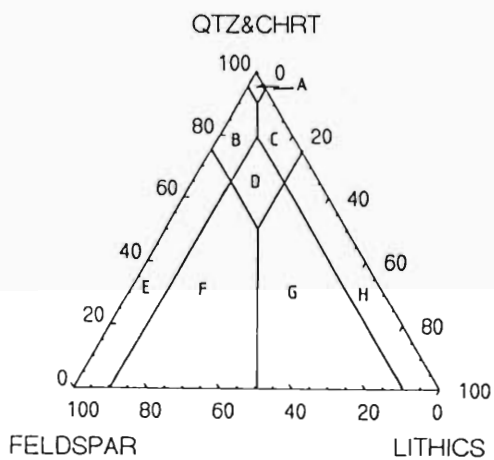
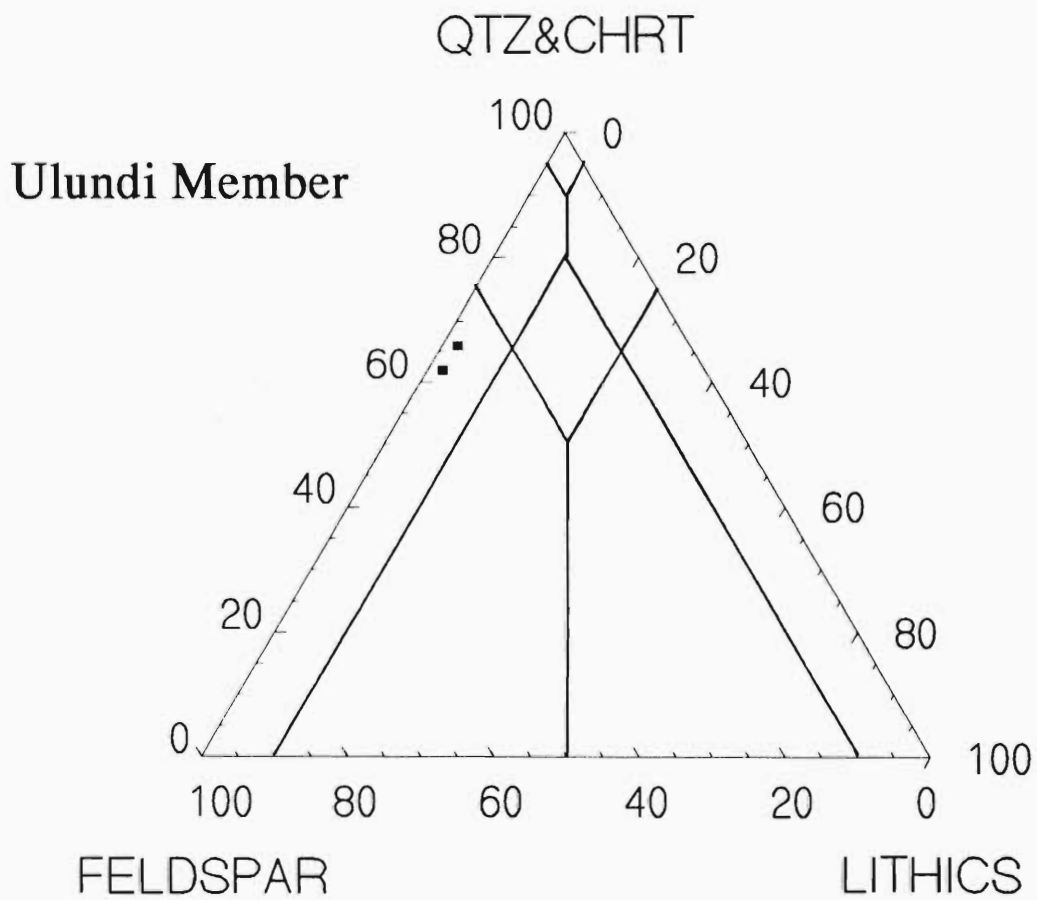
transverse to the current during normal flow. Under reduced flow conditions, the clasts become aligned parallel to the current direction, and move by sliding, under low-flow conditions. Typically, the Ulundi Member conglomerate is well stratified (Fig. 3.2), but individual associated beds are massive and unsorted (Fig. 3.3), with sparse matrix.

Sandstone: The associated sandstone occurs as lenticular beds within the conglomerate, constituting 10-15% of the whole, with a tendency to be isolated. The reddish-grey beds are between 0,1 and 0,4 m thick, with a lateral extent of about 20 to 25 m, and are conglomeratic in part. The arkosic sandstone (Fig. 3.10, Table App-3.4) is poorly sorted, with planar cross bedding indicating a palaeocurrent direction from northeast to southwest.

Shale: The reddish-grey shale also occurs as lenticular beds 0,1 to 0,4 m in thickness and 5 to 15 m in lateral extent, and constitutes approximately 5% of the Ulundi Member. Apart from shaly lamination, the beds are structureless, but are seen to be draped over the larger clasts protruding from the conglomerate bed beneath (Fig. 3.11).

3.1.1.3 Other Occurrences of the Ulundi Member

Situated immediately west of Loliwe Station on the Vryheid-Richards Bay railway line, 700 m east of the 1987 tunnel, 5 km west of Ulundi, is an erosional window in the Dwyka Group rocks, in which are exposed rocks of the Pongola Supergroup. A railway cutting excavated within this window, along a realignment of the railway line, has revealed the presence of a palaeotalus deposit which was formed immediately prior to the onset of the Natal Group deposition. The relationships between the various lithologies (metavolcanic floor, palaeotalus, argillaceous rocks, arenaceous rocks, Dwyka Group cover) in this cutting are illustrated in Fig. 3.12.



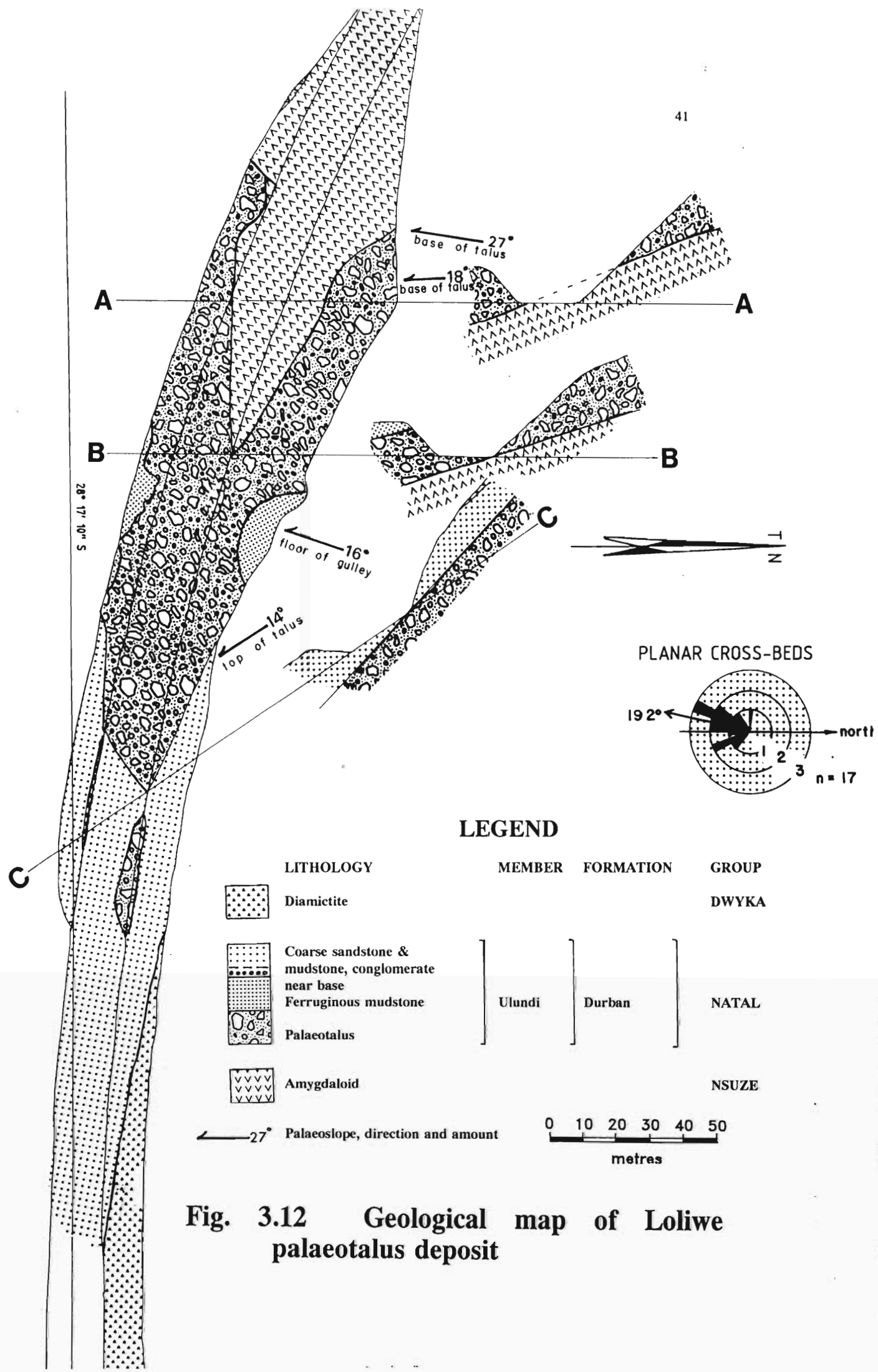
- | | |
|----------------------|-----------------------------|
| A = Quartzarenite | E = Arkose |
| B = Subarkose | F = Lithic Arkose |
| C = Sublitharenite | G = Feldspathic Litharenite |
| D = Lithic Subarkose | H = litharenite |

Fig. 3.10 Composition of Ulundi Member sandstones

3. DESCRIPTION OF NATAL GROUP UNITS



Fig. 3.11 Ulundi Member conglomerate with interbedded shale band draped over boulder protruding from lower bed, south bank of White Mfolozi River, south of Ulundi.



28° 17' 10" S

A

B

C

27°
base of talus

18°
base of talus

16°
floor of gulley

14°
top of talus

PLANAR CROSS-BEDS

192° north

n = 17

LEGEND

LITHOLOGY	MEMBER	FORMATION	GROUP
Diamictite			DWYKA
 	Ulundi	Durban	NATAL
			NSUZE

27° Palaeoslope, direction and amount

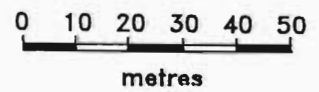


Fig. 3.12 Geological map of Loliwe palaeotalus deposit

Morphology: The palaeotalus occurs on the steep (18° to 27°), south-facing slope beneath a kran of Pongola Supergroup quartzite which is now partly obscured by rocks of the Dwyka Group. The exposed portion of the palaeotalus measures 180 m from east-west, and is estimated to be approximately 200 m from north to south. The maximum thickness is estimated to be 15 m (Marshall, 1991a). It should be understood that the thickness of an irregular body such as this palaeotalus deposit will have a considerable lateral variation.

Lithology: The palaeotalus consists of a haphazard accumulation of very angular blocks and fragments of pale, greyish yellow green quartzite which range in size from a few centimetres to more than 7 m (Fig. 3.13a). There is a concentration of larger blocks in the central portion of the occurrence. The interstices have been filled by horizontally-layered, greyish red to dusky red, micaceous, silty to sandy mudstone. This same mudstone fills some of the hollows in the irregular surface (Fig. 3.13a). A modern talus deposit, formed by a rock avalanche as defined by Blair and Mc Pherson (1994) is illustrated in Fig. 3.13b for comparison.

The argillaceous unit overlying the palaeotalus is seen to be the oldest unit of the fluvial rocks of the Eshowe Member, and consists of a ferruginous, greyish red to dusky red, micaceous silty to sandy shale which has crude stratification (Fig. 3.13a). It occurs in depressions in the irregular upper surface of the palaeotalus, and as the matrix of the palaeotalus. The maximum thickness is 2 m. The floor of the major depression slopes at 16° in a direction of 200° (Fig. 3.12).

The arenaceous unit, which stratigraphically overlies the argillaceous unit, is a greyish pink, coarse- to very coarse-grained, poorly-sorted, immature, arkosic sandstone. In parts it is

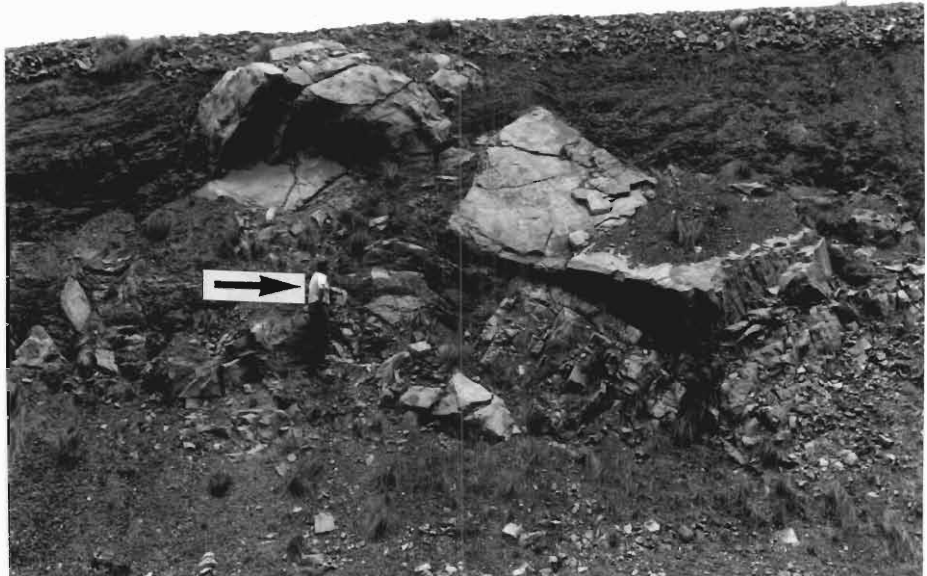


Fig. 3.13a Loliwe palaeotalus deposit (Ulundi Member) showing haphazard accumulation of angular, poorly-sorted blocks of quartzite, and an overlying deposit of stratified shale (Eshowe Member), west of Ulundi (Photo: V. von Brunn, human figure for scale)



Fig. 3.13b Exhumed palaeokrans of Pongola Supergroup with modern avalanche talus deposit, west of Ulundi.

a polymict, small-pebble clast-supported conglomerate, with clasts up to 10 mm in diameter. The clasts are well-rounded and consist of quartz, chert and jasper. The accessible portion (not obscured by Dwyka Group cover) is 14 m thick. The dominant primary sedimentary structure is planar cross-bedding which indicates a palaeocurrent direction from northeast to southwest, roughly parallel to the present strike of the floor, which slopes to the southeast at 14°. The bedding is of the order of 30 cm thick, and is horizontal, the latter, in conjunction with the steep slope of the palaeofloor, indicates that this occurrence represents valley-fill. Soft-sediment deformation of the beds indicates slumping of the sediments, initiated, possibly, by instability of the sediments on the relatively steep slope of the palaeofloor, as discussed in Chapter 6. Deposition.

It is argued that the Loliwe palaeotalus deposit is one of many similar contemporaneous deposits which were the source of the well-rounded quartzite clasts which make up the typical Ulundi conglomerate, and the Loliwe deposit has thus been included stratigraphically in the Ulundi Member of the Durban Formation. The greyish red colour of some of the Ulundi Member clasts would have been derived during the transport from the source to the depositional site, while other clasts are coloured red throughout, and were derived from a red quartzite. The arenaceous and argillaceous units have been included in the Eshowe Member, as there is no lithological or stratigraphic reason to do otherwise.

In the far south of the basin, at the positions indicated (Fig. 3.15), there is a conglomerate, usually matrix supported, polymict (quartz, quartzite and chert), with moderately-rounded clasts (Fig. 3.15). The clast packing density is estimated at 45%. The author has included this in the Ulundi Member.



Fig. 3.14 Ulundi Member conglomerate from near the southern limit of the basin, near Ntabakucasha.

3.1.2 ESHOWE MEMBER

3.1.2.1 General The Eshowe Member is the most widely-distributed unit of the Natal Group, and is present everywhere in the basin (Figs. 3.15; App-2.15). The name of this member was introduced by P.E. Matthews (in SACS, 1980), who identified the type area as the vicinity of Eshowe. The Eshowe Member consists essentially of sandstone with subordinate interbedded shales and siltstones. Over most of the basin it lies unconformably on the granitic and supracrustal Precambrian basement rocks (Fig. 3.16), except where it rests on the Ulundi Member (Fig. App-2.15).

3.1.2.2 Thickness: The thickness ranges from 0,7 to 142 m (Table 3.2). The isopach map of the Eshowe Member (Fig. 3.15) reveals a deep trough which, because of a lack of data, appears to be open-ended to the northeast. It also shows that the deepening of the basin from the lateral margin towards the central axis is much more rapid in the north than in the south. Of interest is a basement ridge - trending NE-SW - in the vicinity of Pietermaritzburg. Along this Pietermaritzburg Ridge the Dwyka Group rests directly on the basement rocks.

The thickness variation is attributed, in part, to the highly irregular palaeorelief of the basin-floor. However, the main factor determining the variation in thickness would seem to be the position within the basin. Both the mean and maximum thicknesses increase southwards from the northern limit of the basin to a maximum in the Eshowe area, and then decrease southwards to a minimum at the southern limit of the basin. The apparently anomalous decrease in thickness in the Kranskop area merely reflects the thinning of the

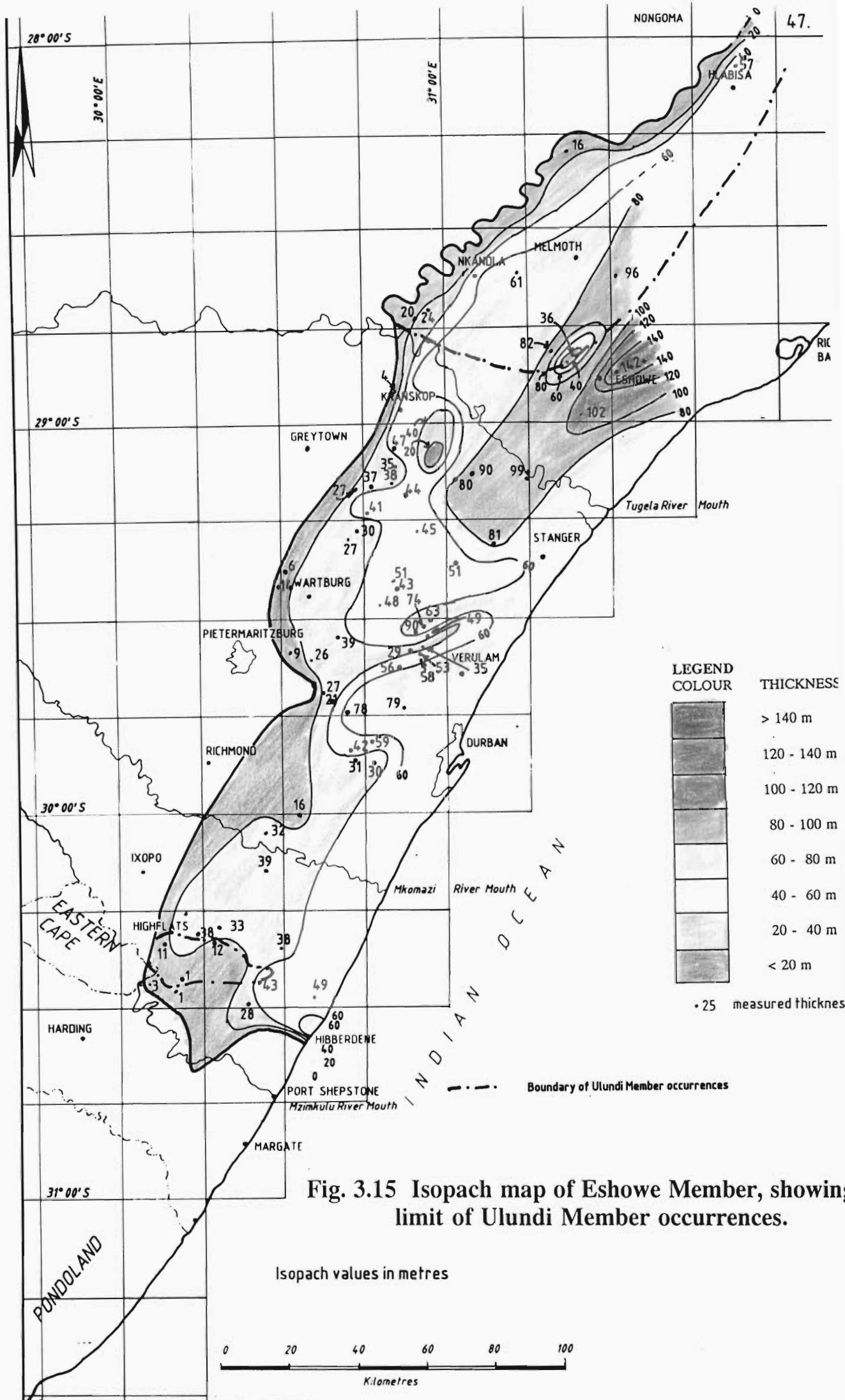


Fig. 3.15 Isopach map of Eshowe Member, showing limit of Ulundi Member occurrences.

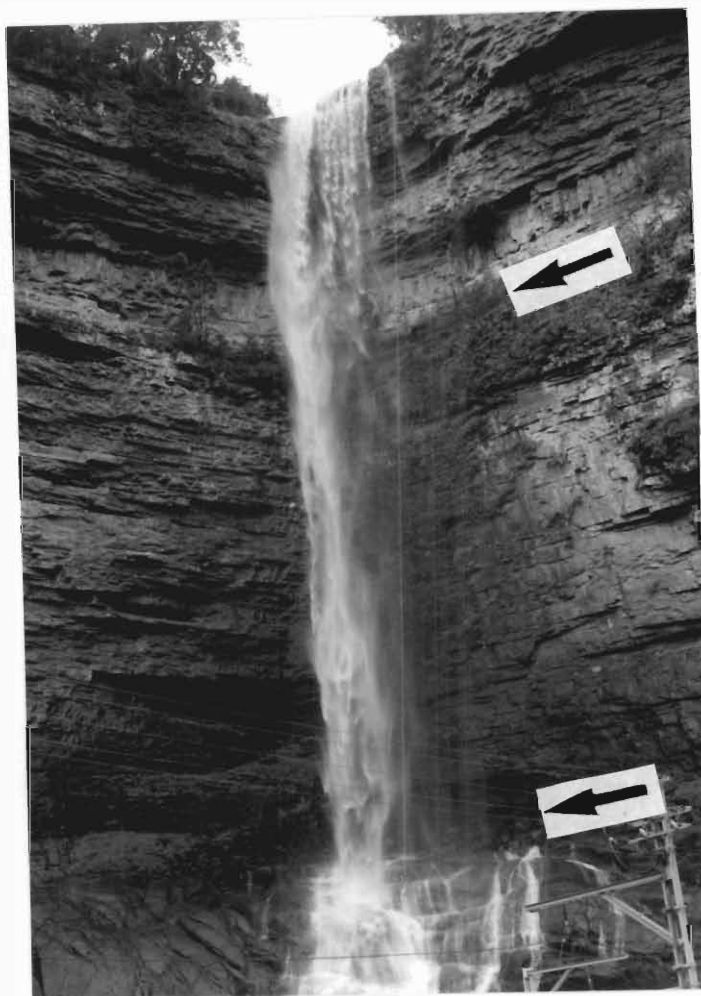


Fig. 3.16 Eshowe Member overlying basement granite unconformably, and conformably overlain by Kranskloof Member at Shongweni Falls. Contacts marked by arrows.

Table 3.2 Thickness of Eshowe Member (metres)

AREA	NUMBER OF SECTIONS MEASURED	MEAN THICKNESS	MINIMUM THICKNESS	MAXIMUM THICKNESS
MELMOTH	6	57,75	16,0	96,0
ESHOWE	7	89,7	35,5	142,5
KRANSKOP	24	32,8	4,0	67,5
DURBAN	19	47,9	15,0	79,5
SOUTHERN K'-NATAL	16	24,2	0,7	48,5
OVERALL	75	44,0	0,7	142,5

unit towards the western margin of the basin. Thicknesses of less than 10 m for the Eshowe Member are revealed in several sections measured near its southern periphery, and thus reflect thinning of the unit at its extremities.

3.1.2.3 Lithology The Eshowe Member consists of interbedded quartz arenites, sub-arkosic to arkosic sandstones, siltstones and shales. The finer rocks are usually micaceous and darker in colour than the coarser varieties. The Eshowe Member consists of 85-95% coarse- to very coarse-grained, immature, poorly-sorted, sandstones, with subordinate interbedded shales and siltstones. The colour ranges from greyish red to dusky red. Moderately rounded clasts of quartz, quartzite and jasper, 5-30 mm in diameter, are widely dispersed within the sandstone. The clasts also occur commonly as single-layer lag conglomerates throughout the unit, whereas pebbly lenses, approximately 15 cm thick, occur near the base of the Eshowe Member (Fig. 3.17). Rip-up clasts of reddish micaceous shale are common in the sandstones (Fig. 3.18).

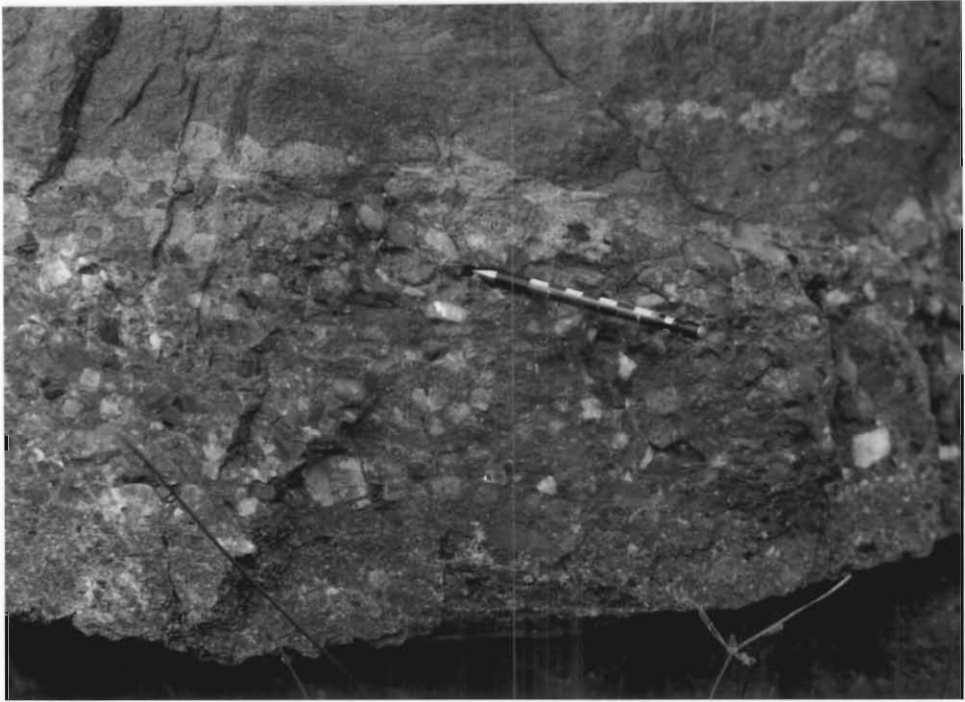


Fig. 3.17 Small-pebble conglomerate lens near base of Eshowe Member, near Ulundi

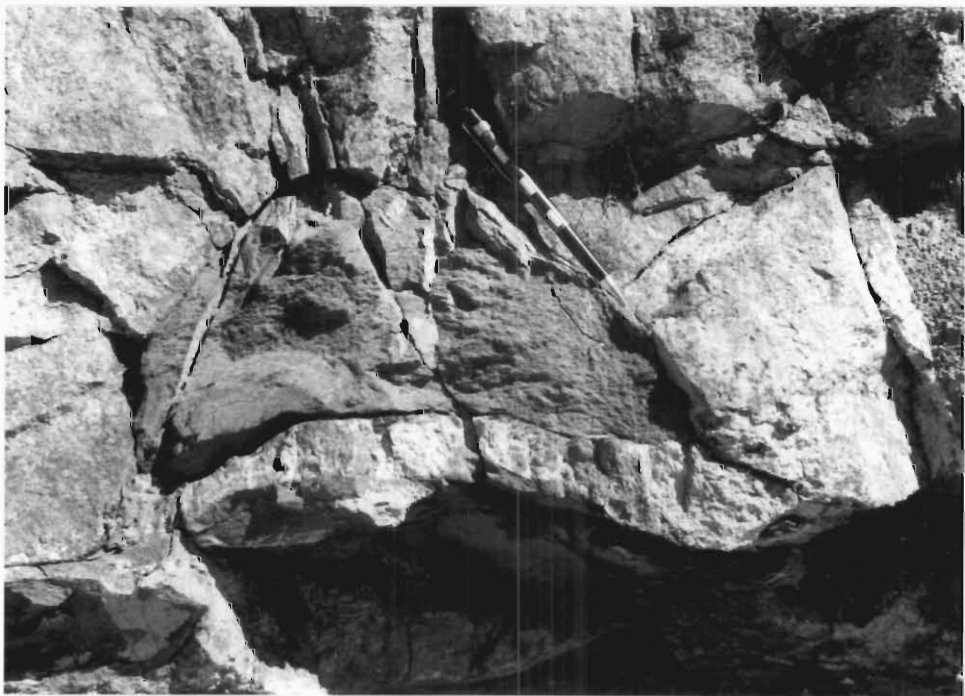
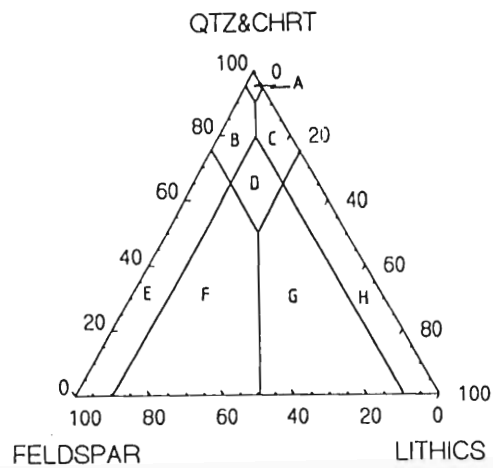
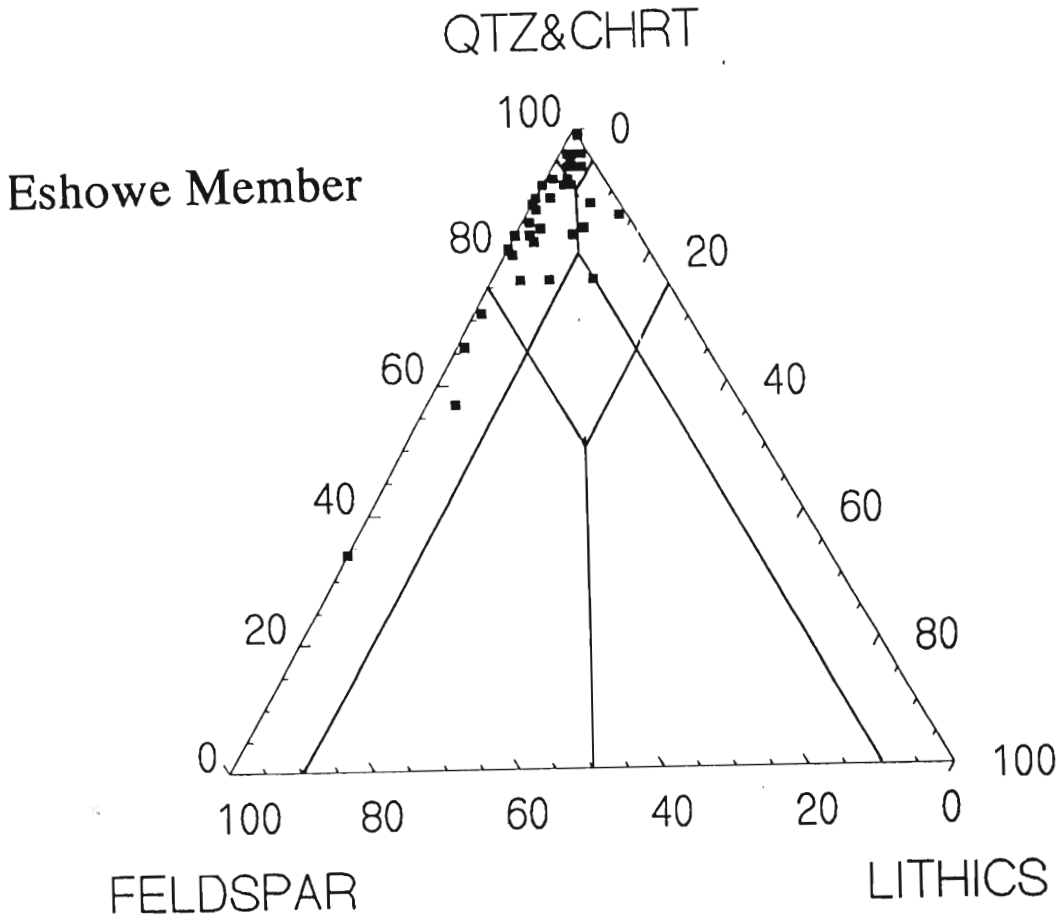


Fig. 3.18 Rip-up clast of purple mudrock in Eshowe Member sandstone, SE of Greytown

The arenaceous rocks constituting the Eshowe Member fall mainly into the sub-arkose and quartz-arenite fields of the Mc Bride (1963) sandstone classification, with minor occurrences within the arkose and sub-litharenite fields (Fig. 3.19). A lithology encountered commonly in the Eshowe Member, is a silicified, very coarse-grained arkose, whose reddish colour is due largely to red orthoclase present in the rock (Fig. 3.20). At Wood Grange near Hibberdene and Mahlabatshane south of Highflats, the basal beds of the Eshowe Member are extremely coarse, with large, angular fragments of quartz and unweathered feldspar.

Interbedded in the sandstones are beds of greyish red to dusky red shale and siltstone with an estimated 10-15% fine white muscovite - both authigenic and allogenic (Thomas *et al.* 1992). The shale beds are of the order of 5-30 cm thick and up to 30 m in lateral extent (Fig. 3.21 and see measured sections, Figs. App-1.3 to App-1.27).

A very common structure noted in the Natal Group is reminiscent of a reactivation surface, except that the cross-bedding set below the discontinuity - marked by a clay drape a few centimetres thick - is not bevelled according to the description of a reactivation surface by Klein (1970) and Collinson and Thompson (1982). The author suggests that under some circumstances, such as protective armouring by clay drapes deposited during periods of reduced flow and quiescence, and exposure to the air enhancing the cohesive strength of the clay, the underlying cross-beds would be protected against the erosive effects of the subsequent moderate flow regime event (as evidenced by the tabular cross beds - see Harms and Fahnestock, 1965) No bevelling would take place, and the cross-bedded set would be extended downstream. It is thus proposed to include this feature, which in effect



- | | |
|----------------------|-----------------------------|
| A = Quartzarenite | E = Arkose |
| B = Subarkose | F = Lithic Arkose |
| C = Sublitharenite | G = Feldspathic Litharenite |
| D = Lithic Subarkose | H = litharenite |

Fig. 3.19 Composition of Eshowe Member sandstones



Fig. 3.20 Very coarse-grained sandstone to granule-conglomerate with orthoclase imparting red colour to the rock, south of Mid Illovo.



Fig. 3.21 Thin beds of shale in Eshowe Member. Stick is 1,5m in length, south of Ulundi.

marks an interruption and reactivation in the formation of a bed, under the term "reactivation surface". On occasions, when the erosive effect of the river exceeded the cohesive strength of the clay layer, these argillaceous deposits appear to have served as a source for rip-up clasts occurring in succeeding sandstone beds (Fig. 3.18).

Although the Eshowe Member consists predominantly of arenaceous sediments with subordinate interbedded greyish red to dusky red micaceous shale with a lenticular habit (Fig. 3.22), there are also localities where the argillaceous sediments are dominant. While the shale beds in the Eshowe Member are usually of the order of 5 to 30 cm thick and 15 to 30 m in lateral extent, and usually occurring individually, there are occurrences where a shale unit exceeds 3 m in thickness. The base of the Eshowe Member usually comprises coarse-grained, arkosic sandstone, but there are several localities where shale several metres thick is developed at the base.

A sample of siltstone taken from near the top of the Eshowe Member, a few hundred metres upstream from the bridge on the old South Coast road, over the Mtwalume River, contained clastic particles now consisting of illite. These have been identified by Fitch (Thomas *et al.* 1992), from their typical shape, and from the fact that the feldspars in the sample are all unaltered, as originally having been glass shards. This is the first recorded evidence of volcanic activity contemporaneous with the deposition of the Natal Group.

K-Ar and $^{40}\text{Ar}/^{39}\text{Ar}$ isotopic data from the same samples reveal a complex history of isotopic resetting. Pan-African K-Ar ages of ~580 Ma were obtained from detrital muscovites, whereas secondary clay fractions suggest major K-Ar components at ~400,



Fig. 3.22 Eshowe Member sandstone with interbedded purple shale and siltstone. Note lenticular habit of beds, south of Kranskop. Stick is 1,5 m in length.

~350, and ~260 Ma. The last event reflects partial overprinting during the Cape orogeny, but the significance of the older dates is less certain. $^{40}\text{Ar}/^{39}\text{Ar}$ spectrum analyses of the two samples suggest that the Natal Group was deposited at ~490 Ma (See Thomas *et al.* 1992).

3.1.2.4 Primary Sedimentary Structures Sandstone beds are the dominant feature in the Eshowe Member, and constitute some 75-90% of the whole, but interbedded shale is common, occurring as beds or very thin (one or two centimetres thick) drapes separating the sandstone beds. A typical situation is illustrated in Fig. 3.22 where both tabular and lenticular beds of sandstone and shale occur. Bed thicknesses vary between 15 cm and 1,0 m for the arenaceous rocks, with an estimated average bed thickness of approximately 30 cm. The very coarse sandstone beds vary in thickness between 30 cm and 2,0 m, with an estimated average of 45 cm, thus confirming the observation by Roberts (1981). The argillaceous beds are 5 to 30 cm thick, with an average of approximately 20 cm. The thicker argillaceous beds are rare, especially in the lower portion of the member south of Eshowe. Lateral extent of the beds is from a few metres to 50 m, the thicker beds usually being the more persistent. A typical overall view of the outcrop pattern of the Eshowe Member overlying granite is seen at Tsheni, where it is capped by the more resistant Kranskloof quartz-arenites. (Fig. 3.23).

The majority of the sandstone beds are either structureless or have horizontal lamination, with laminae of the order of 10 mm thick. Parting lamination has been observed on bedding surfaces. Current ripples are rare. Where internal sedimentary structures are developed, they occur as planar and trough cross-beds. Lenticular bedding, wavy bedding, scour

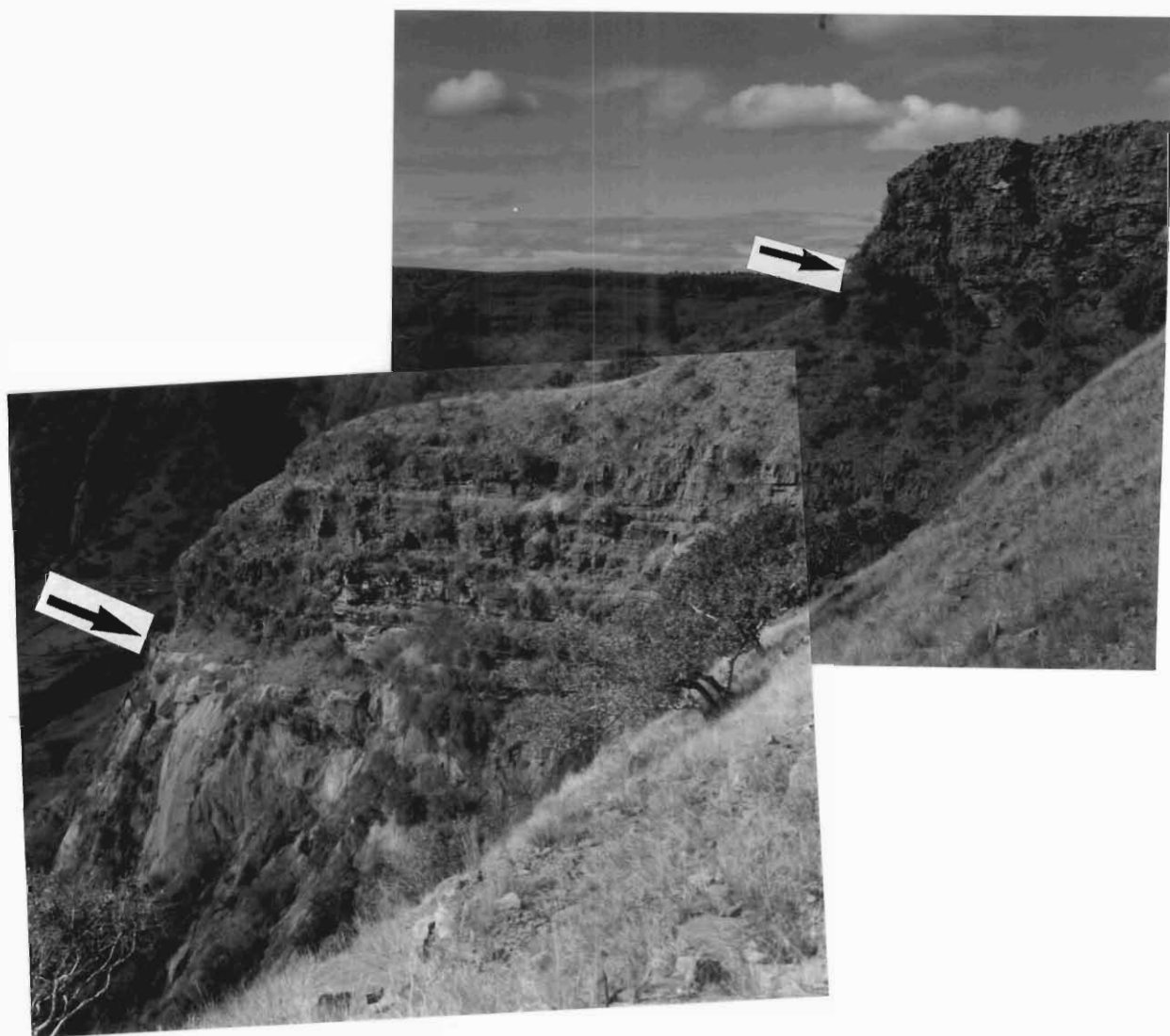


Fig. 3.23 Eshowe Member resting on basement granite, and overlain by resistant Kranskloof Member, near Tsheni. Contacts marked by arrows.

surfaces, graded foresets and reactivation surfaces have also been noted.

Planar cross-bedding usually occurs as solitary sets, or sets alternating with massive or horizontally-laminated beds, but there are occurrences of co-sets of two or more stacked sets. Planar cross-bedding sets are of the order of 30 cm thick, with foreset beds approximately 5 to 15 mm thick. However, there are several occurrences of planar cross-bedded sets 2 m thick (Fig. 3.24). Locally, in the northern portion of the basin, trough cross-bedding (Fig. 3.25) is more prevalent than planar cross-bedding.

Erosion channels, 15 to 30 cm deep and 1 to 2 m wide, which have been filled with very coarse sand and rip-up clasts of shale (Fig. 3.26), or with sandstone occur commonly.

In the northern portion of the basin, soft-sediment deformation occurs throughout the Natal Group sedimentary pile, from within a few metres of the base (Fig. 3.27, slump structure). Other common soft-sediment deformation structures are convolute bedding (Fig. 3.28) and water escape structures (sand volcanoes) (Fig. 3.29). Southward, it becomes progressively restricted to the higher stratigraphic levels of the succession until, south of Durban, it is noted only within the Newspaper Member of the Mariannahill Formation (Matthews, 1961, confirmed by the author).



Fig. 3.24 Set of planar cross-beds in excess of 2 m thickness, south of Eshowe. Stick is 1,2 m long.



Fig. 3.25 Trough cross-bedding in Eshowe Member, NW of Eshowe



Fig. 3.26 Scour channel filled with coarse sandstone and rip-up clasts of shale, WSW of Eshowe.



Fig. 3.27 Slump structure in Eshowe Member, a few metres above the base, north bank of White Mfolozi River, south of Ulundi.

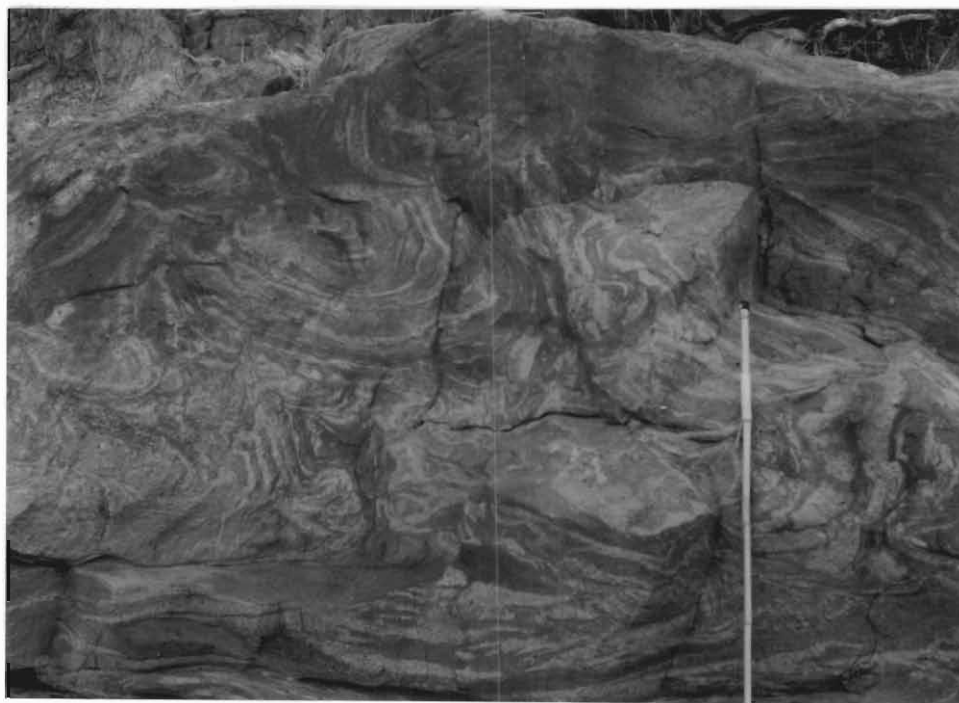


Fig. 3.28 Convolute bedding in Eshowe Member, SSE of Melmoth. Stick is 1,5 m long.

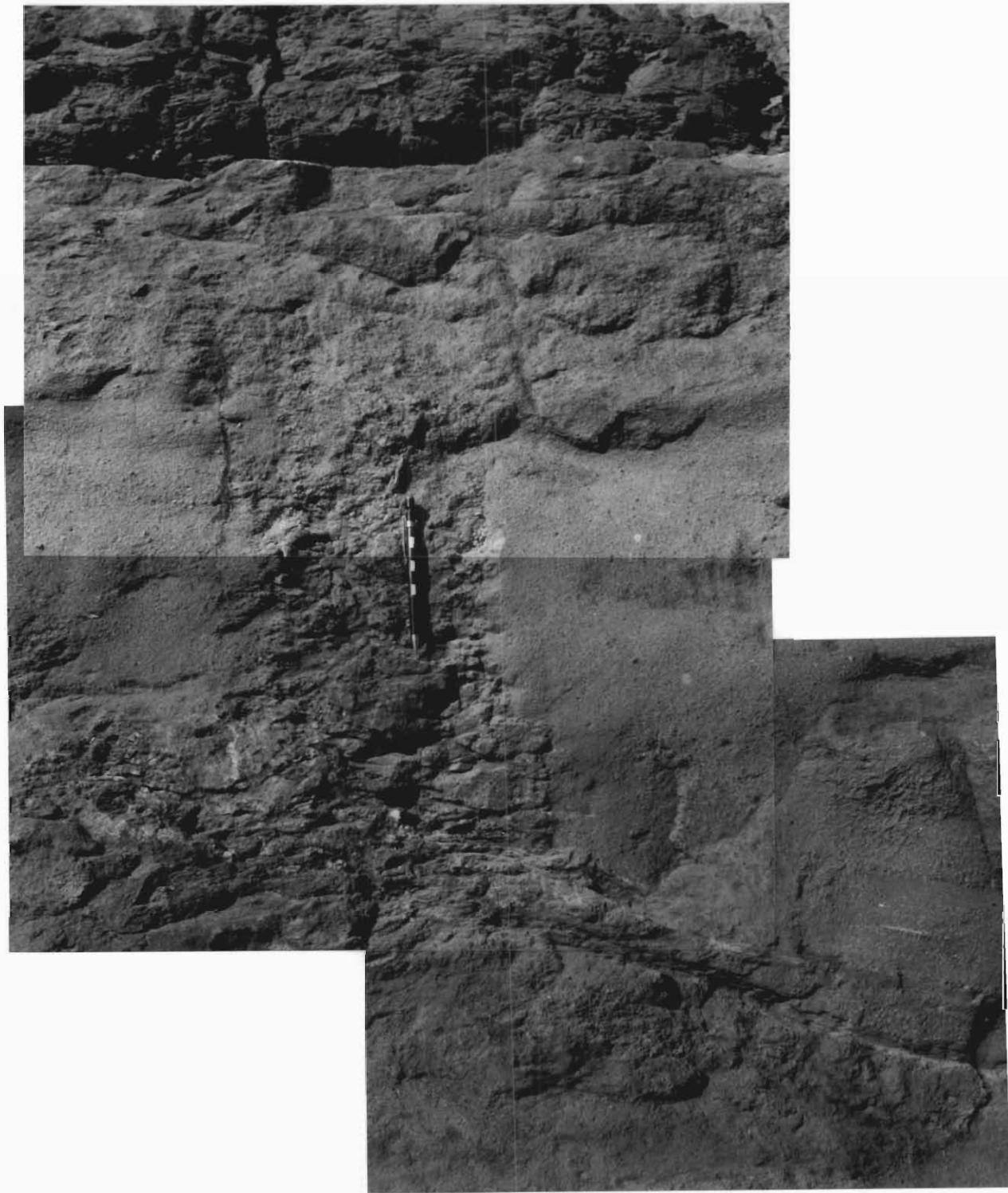


Fig. 3.29 Internal structure of a sand volcano (water escape structure) near Tulini.

3.1.3 KRANSKLOOF MEMBER

3.1.3.1 General The Kranskloof Member occurs from just south of the Mhlatuze River in the north to Hibberdene at the southern limit of the basin, and from the present KwaZulu-Natal coastline in the east to very close to the western boundary of the basin (Fig. 3.30; App-2.15). North of the Tugela River its occurrence becomes sporadic. Brauteseth (1970) suggested that the southernmost occurrence of this unit is near Umzinto, but Kingsley (1975), confirmed by the author, identified this unit, albeit much reduced in thickness, as far south as Wood Grange near Hibberdene. It is possible that the quartzitic sandstone intersected in the borehole JC-1 (du Toit and Leith, 1974), some 24 km east of Stanger, is actually the Kranskloof Member. The name was suggested by Roberts (1981) from the Kranskloof Nature Reserve at Kloof west of Durban. The type area is taken as the vicinity of Durban.

The Kranskloof Member is possibly the most conspicuous unit of the Natal Group as, due to its resistant lithology, it almost invariably crops out as kranses, forming the scenery that typifies the Natal Group (Fig. 3.31). Care should be taken, however, not to necessarily equate kranses with Kranskloof, as there are other units within the Natal Group which form kranses locally.

This member consists predominantly of silicified quartz-arenites with subordinate shale bands, overlies the Eshowe Member conformably, and is in turn overlain conformably by the Situndu Member, or paraconformably (Chapter 2.) by either the Tulini Member or the Newspaper Member of the Mariannahill Formation. The relationship to younger units

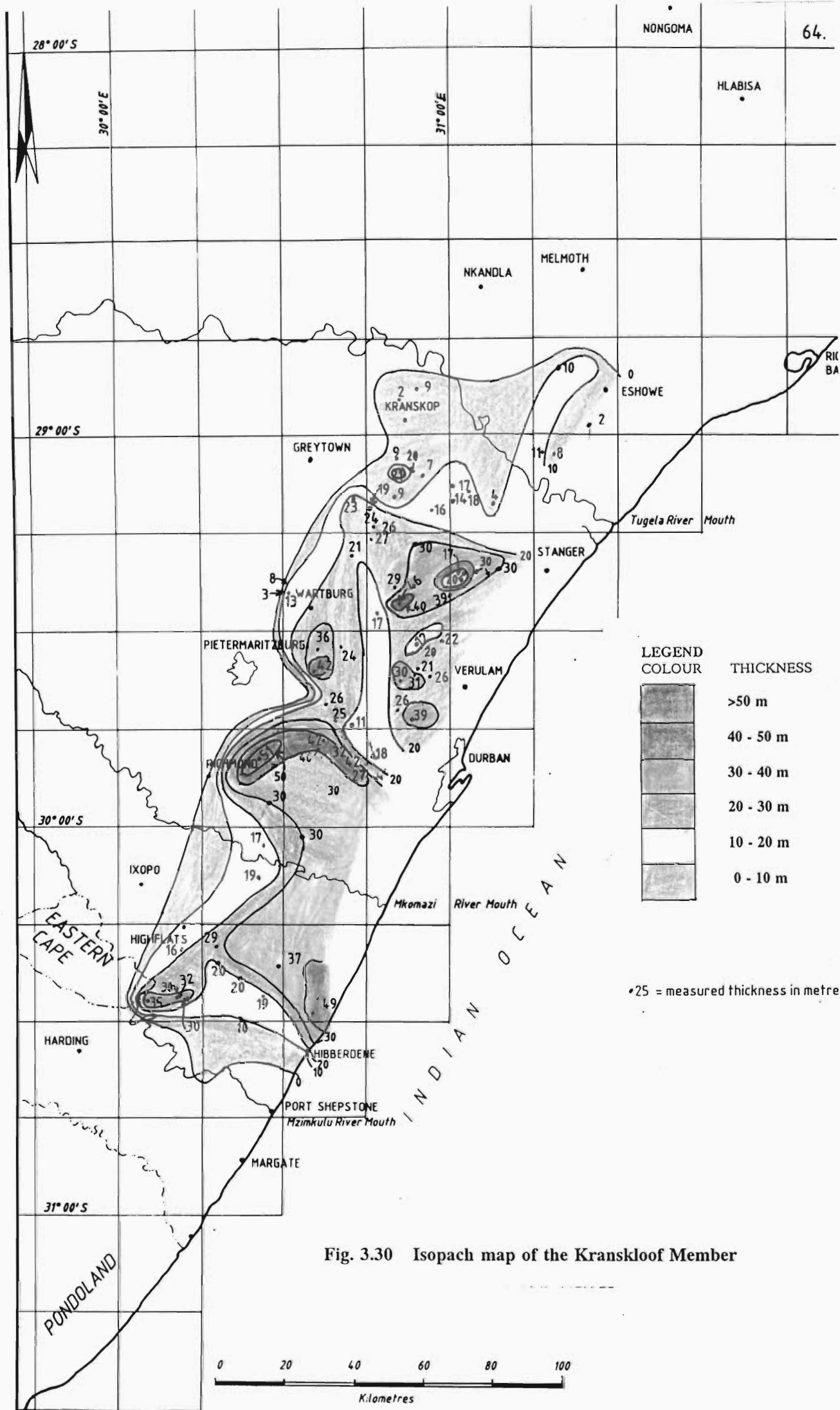


Fig. 3.30 Isopach map of the Kranskloof Member

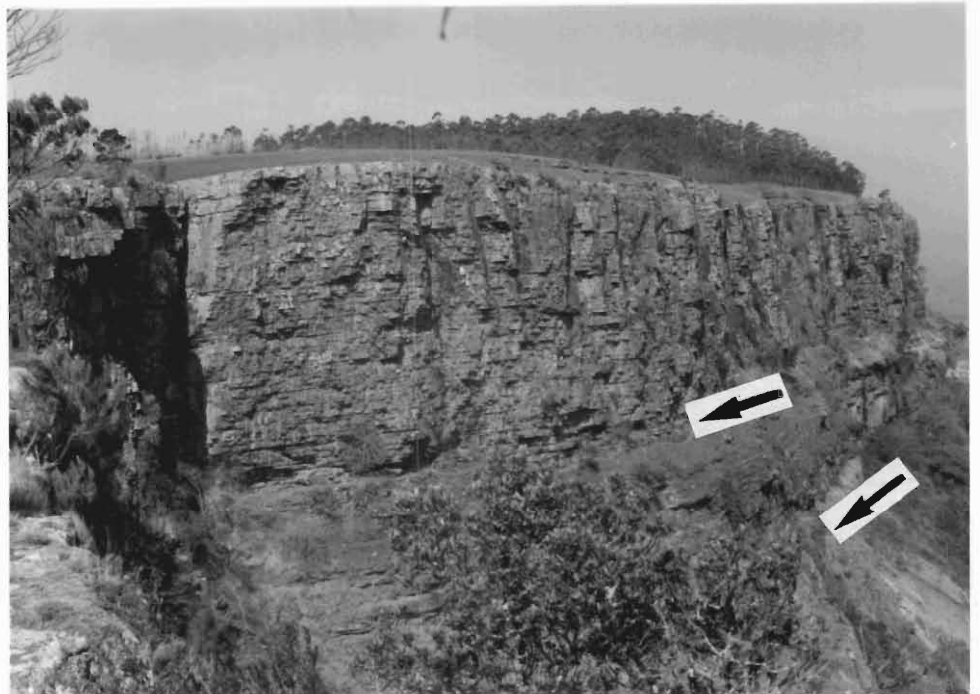


Fig. 3.31 Typical Natal Group kran (near Noodsberg cave) formed by Kranskloof Member (40 m thick) overlying Eshowe Member, in turn resting on basement granite. Note the vertical cleft on the left. Arrows mark contacts.

depends on the geographical position within the basin (Fig. App-2.15).

3.1.3.2 Thickness: Previous workers have reported a remarkably constant thickness of about 20 m for the Kranskloof Member (Rhodes and Leith 1967; Roberts 1981), but the present investigation has revealed an extremely variable thickness. Thicknesses range from 1,5-51 m (Table 3.3). The mean thickness (22,4 m) is very close to the thickness reported by both Rhodes and Leith (1967) and Roberts (1981). Both the mean and maximum thicknesses determined for the above areas of research increase from north to south (Table 3.3; Isopach map, Fig. 3.30). There is a rapid decrease in thickness, not reflected in Table 3.3, at the southern limit. The thickness at Wood Grange reported by Kingsley (1975) is 3 m. The isopach map shows a normal deepening towards the centre of the basin, with a deep trough just south of Pietermaritzburg. The basement ridge east of Pietermaritzburg, discussed in the section on the Eshowe Member (Fig. 3.15), is also evident on the isopach map of the Kranskloof Member.

Table 3.3 Thickness of Kranskloof Member (metres)

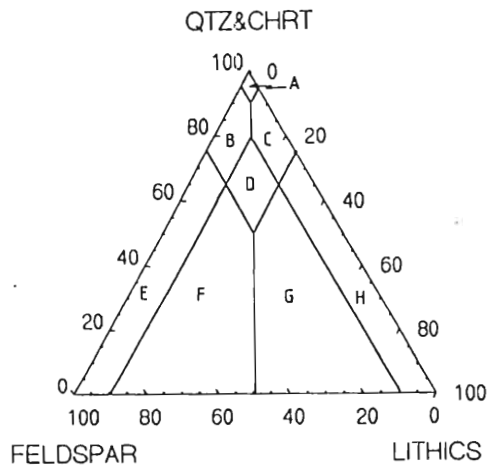
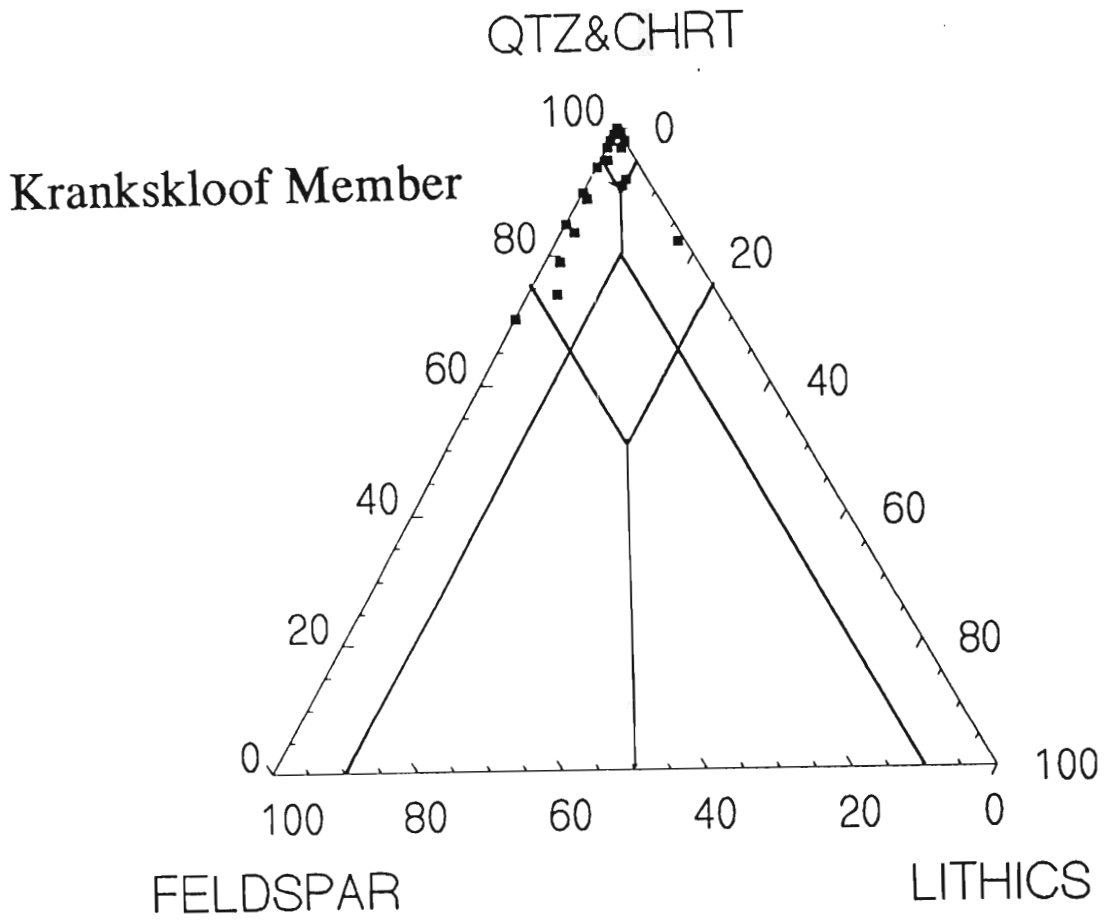
AREA	NUMBER OF MEASURED SECTIONS	MEAN THICKNESS	MINIMUM THICKNESS	MAXIMUM THICKNESS
MELMOTH	1	7,75	7,75	7,75
ESHOWE	10	15,9	1,5	39,0
KRANSKOP	22	20,4	2,2	45,5
DURBAN	26	24,4	11,0	42,0
SOUTHERN K'-NATAL	17	26,8	9,5	50,7
OVERALL	76	22,4	1,5	50,7

3.1.3.3 Lithology

Arenaceous Rocks: The Kranskloof Member consists mainly of silicified sandstones which plot in the quartz arenite and sub-arkose fields of Mc Bride (1963) (Fig. 3.32). The colour of the sedimentary rocks of the Kranskloof Member varies from dusky red and very dark red through greyish pink to greenish grey, with a preponderance of greyish red to pale red. Liesegang bands occur commonly in the quartz-arenites of the Kranskloof Member. The Kranskloof arenaceous rocks consist of quartz and chert, feldspar (mainly microcline), sericite and accessories including zircon, muscovite, haematite, hornblende and garnet. The quartz content varies from 66% to 98% (Table App-3.2), figures lower than the quartz content given by Roberts (1981). However, it seems that Roberts included the secondary quartz (cement) in his ternary diagrams, with the result that the rocks appear to be quartz-arenites rather than sub-arkoses. The composition of the Kranskloof sandstones are thus not as consistently pure as has been suggested by Roberts (1981).

Quartz cement is very common, occurring as overgrowths in optical continuity with the detrital quartz grains (Fig. 3.33). The red colour of the rocks is caused by haematite staining of the quartz grains, present as a 'dust rim' on the original surfaces. The microcline grains are unweathered. Roberts (1981) reported on the presence of secondary potash feldspar, and during the current study. The occurrence of secondary overgrowths of microcline on microcline was noted. North of Stanger, the Kranskloof Member is not as well silicified or as mature as south of Stanger, with a resultant northward decrease in the prominence of topographic expression.

Argillaceous Rocks: Interbedded with the sandstones are subordinate lenticular bodies of

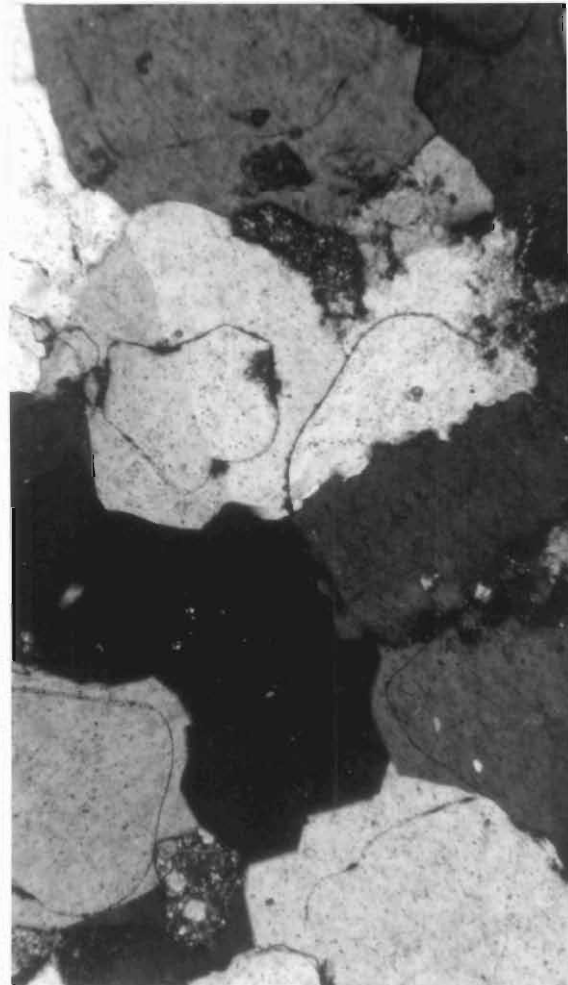


- | | |
|----------------------|-----------------------------|
| A = Quartzarenite | E = Arkose |
| B = Subarkose | F = Lithic Arkose |
| C = Sublitharenite | G = Feldspathic Litharenite |
| D = Lithic Subarkose | H = litharenite |

Fig. 3.32 Composition of Krankskloof Member sandstones



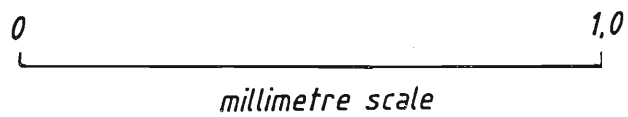
a) Plane-polarized light



b. Crossed polarizers

Fig. 3.33 Photomicrographs showing dust rim on original quartz grains.

Magnification 76,5x



shale and siltstone (Fig. 3.34). The even reddish colour of the argillaceous material has been modified diagenetically to produce pale bleach spots (Roberts, 1981). At the base of the Kranskloof Member in the vicinity of Durban and Pietermaritzburg is a sequence of interbedded quartz-arenites, arkosic sandstones, siltstones and shales. Roberts (1981) interpreted them as intertidalites, but the author would prefer the term "transition beds", as this describes the transition from the Eshowe Member to the Kranskloof Member without any environmental implication. Sparsely distributed rip-up clasts of greyish-red shale, occur within the quartz-arenites.

At several localities, the normal, well-silicified quartz arenites are interrupted by a zone in the stratigraphic centre where the rocks are sub-arkosic and poorly silicified (Stratigraphic section Fig. App-1.19). This central zone has a less-pronounced outcrop expression.

3.1.3.3 Primary Sedimentary Structures: Bed thicknesses vary between 0,1 and 1,5 m, with a predominance in the region of 0,3-0,5 m. Lateral extent of beds varies between 5 m and 20 m. Lenticular bedding is a common feature. The relatively rare argillaceous material ranges in thicknesses from a few centimetres to 15 cm, and is invariably lenticular (Fig. 3.34).

The quartz arenites of the Kranskloof Member are either massive, or have horizontal stratification as the most common sedimentary structure. Laminae and very thin beds are of the order of 5-20 mm thick. Current ripples and planar cross-bedding also occur, but are scarce. Reactivation surfaces occur in the transition beds at the base of the Kranskloof Member. Planar cross-bedding (rarely low-angle) occurs, but not abundantly. Rhodes and



Fig. 3.34 Thin, lenticular shale lenses (arrow) in Kranskloof Member quartzarenite, near Appelbosch.

Leith (1967) reported the occurrence of rill and swash marks on the bedding planes, but these were not observed during the current study. Channel scours up to 1,5 m deep by 20 m wide are fairly common.

3.1.3.4 Imposed Features

A. Cleft Features: A common feature of the Kranskloof Member is the presence of vertical to near-vertical clefts thought to have been formed by the removal of material from fracture zones or weathered dolerite dykes. These clefts are of the order of 1-5 m wide, up to 40 m deep and 100 m long (Fig. 3.31). There is evidence of either fracturing or dolerite intrusion. Very little, if any, vertical movement took place along the fracture planes. The presence of colluvium derived from the Natal Group, and partially infilling the gaps, hinders the investigation of the floor.

B. Karst Features: A further characteristic feature of the silicified quartz arenites of the Kranskloof Member is the surprising occurrence of karst phenomena such as sink-holes and dolines, invariably marked, at surface, by the presence of trees and shrubs taking advantage of the protection and the provision of water afforded by the depressions.

An example of this occurs near Noodsberg (Fig. 1.1), where access is gained to a solution cave via a sink-hole. Several tunnels, totalling approximately 100 m in length, lead off the sink-hole. The roof of the cave consists largely of small-pebble conglomerate of the Tulini Member, and the sidewalls of the cave comprise friable quartz arenite of the Kranskloof Member (Fig. 3.35). About 1 km further south, near the farm homestead, there is a doline some 30 m in diameter, and with a depression of about 3 to 4 m. Dolines and sink-holes



Fig. 3.35 Roof of Noodsberg cave (Fig. 1.1) at contact between Tulini Member above and Kranskloof Member below. (Bat for scale)

are common features where the present land surface lies at or just above the top of the Kranskloof Member.

The quartz-arenite, which elsewhere is well-silicified and indurated, is seen, in the side-walls of the cave, to be extremely friable. This has resulted from the dissolution of the silica cement from between the framework grains, and the gradual collapse of the side-walls. The resulting clean white sand was removed by the flow of underground water. Martini (1979) referred to well-documented karst features in Table Mountain sandstone northwest of Kalk Bay in the Western Cape, as well as in sandstones of the Waterberg Group and quartzites of the Pretoria Group and Black Reef Formation of the eastern Transvaal, reporting in particular on the Kaapsehoop caves. There is no carbonate cement in any of these occurrences or in the Kranskloof quartz-arenite at Noodsberg.

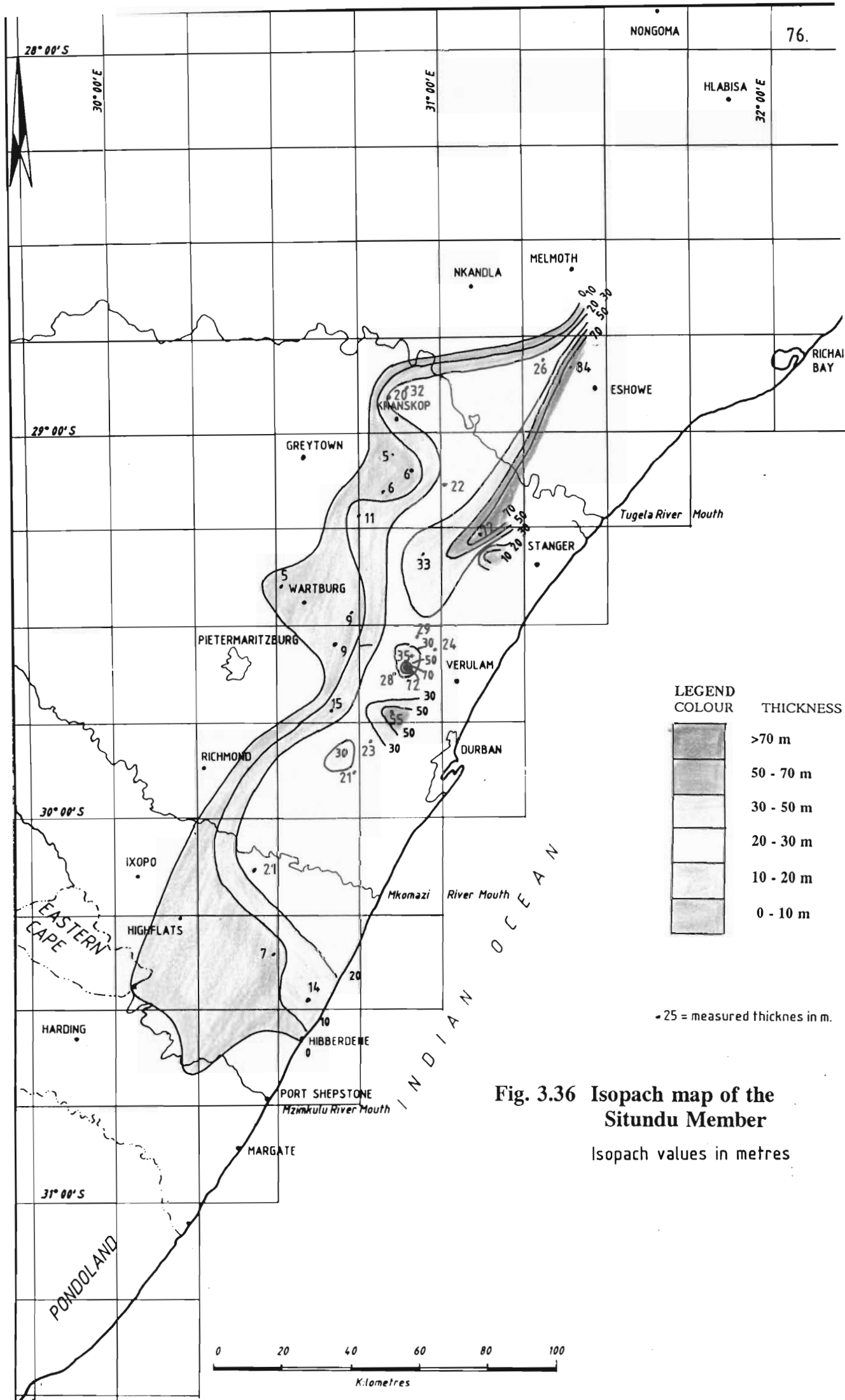
It is necessary to explain the solution of large amounts of silica to form these caves. Millot *et al.* (1959) found that silica in true solution in natural waters occurs as ions of monosilicic acid ($\text{Si}(\text{OH})_4$). The solubility is practically independent of pH, where the pH is less than 9, but at pH values of greater than 9, the solubility of silica increases as a result of the dissociation of $\text{Si}(\text{OH})_4$. They also suggested that pH values of greater than 9 are unlikely in the natural environment. This would imply that it is very unlikely for quartz to be dissolved to any extent in nature. Bennett and Siegel (1987) however, have suggested that organic acids in groundwater can form complexes with silica at nearly neutral pH and near-surface conditions. This could explain the anomalous increased solubility of quartz where the pH of the groundwater is seen to be approximately neutral, and allow for the removal of large quantities of quartz cement from the quartz arenites

where karst features occur.

The restriction of karst phenomena to the quartz-arenites of the Natal Group, is explained as follows: The presence of even trace amounts of aluminium can cause the precipitation of colloidal silica. Precipitation of silica from true solution requires the presence of slightly greater amounts of aluminium (Okamoto *et al.* 1957). The presence of aluminium in a sandstone would thus inhibit the solution and removal of silica, and the solution caves within quartz arenites would thus seem to depend, to a large extent, on the absence of aluminium-bearing minerals such as feldspar or clay.

3.1.4. SITUNDU MEMBER

3.1.4.1 General: The Situndu Member can be identified from just south of the Mhlatuze River in the north, to Hibberdene in the south, and from the coast in the east to the western margin of the basin (Fig. 1.1; 3.36; App-2.15). The name was proposed by Roberts (1981), and the type area is to the southeast of Durban. The main distinguishing feature is that it occurs between the Kranskloof and Dassenhoek Members, from which it is distinguished by the differing lithologies. As the Situndu Member is lithologically indistinguishable, on a regional scale, from the Eshowe and Newspaper Members, its mappability depends on the presence of the Kranskloof Member beneath, and the Dassenhoek or Tulini Member above. Any observable lithological difference between the Situndu Member and the Eshowe or succeeding Newspaper Member, cannot be used for mapping, as similar variations also occur within these other members. Although the unit might well have been developed beyond where it has been recognised, it cannot be



HLABISA
32° 00' E

28° 00' S

30° 00' E

31° 00' E

29° 00' S

30° 00' S

31° 00' S

0 20 40 60 80 100
Kilometres

identified because of the lack of markers which can be used to demarcate its limits. Ideally, the Situndu Member rests on the Kranskloof Member, and is overlain by the Dassenhoek Member. It is also overlain by the Tulini Member where the Dassenhoek Member is absent.

3.1.4.2 Thickness

The thickness of the Situndu Member ranges from 5-84 m with a mean of 25 m (Table 3.4).

Table 3.4 Thickness of Situndu Member (metres)

AREA	NUMBER OF SECTIONS MEASURED	MEAN THICKNESS	MINIMUM THICKNESS	MAXIMUM THICKNESS
MELMOTH	0	--	--	--
ESHOWE	5	41,6	5,0	83,5
KRANSKOP	9	11,3	5,0	33,0
DURBAN	15	29,5	11,5	57,5
SOUTHERN K'-NATAL	3	13,8	7,0	21,0
OVERALL	32	24,8	5,0	83,5

Thicknesses of this unit in the Melmoth area are not reflected, as the member could not be differentiated because of the absence of the Kranskloof Member. There is a progressive decrease in thickness from north to south. The decrease in thickness in the Kranskop area is related to the proximity to the western margin of the basin. On the isopach map of the Situndu Member (Fig.3.36) there is the suggestion of a deeper trough approximately parallel to the present KwaZulu-Natal coastline, and in much the same position as that in

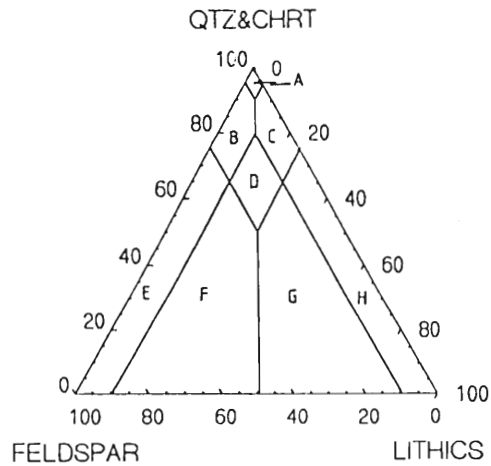
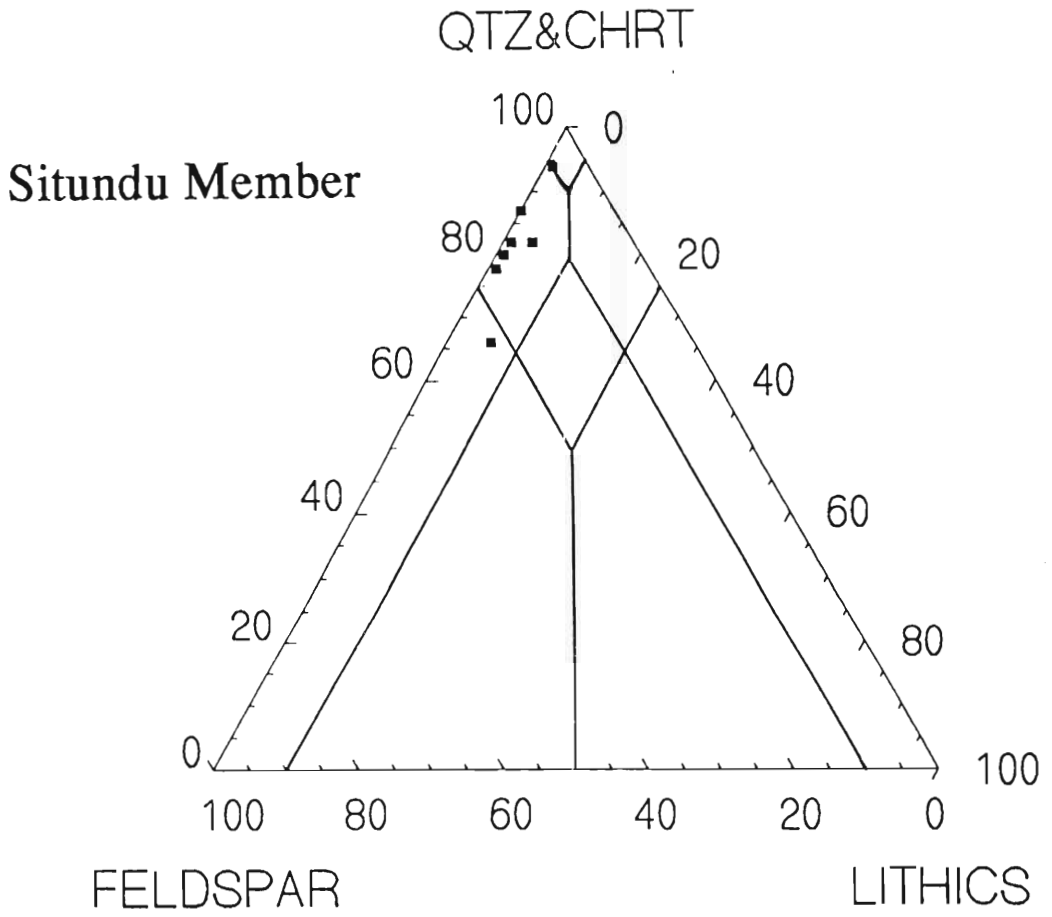
the Eshowe Member (Fig. 3.15). Further, Fig. 3.36 shows that the deepening of the basin from a lateral margin towards the central axis is much more rapid in the north than in the south.

3.1.4.3 Lithology

Arenaceous Deposits: The Situndu Member consists predominantly of coarse, immature, poorly-sorted, pebbly sandstone and subordinate shale. The composition of the sandstone falls within the sub-arkose field of Mc Bride (1963), with one small component in the arkose field and another in the quartz-arenite field (Fig. 3.37). The feldspar grains, both plagioclase and microcline, are unweathered. The greyish-red colour of the sandstones is a result of haematite-staining of individual quartz grains. This haematite is present as a 'dust rim' on the original grain boundaries, many of which display quartz overgrowths. The haematite also occurs as concentrations along the contacts between the overgrowths. The feldspar grains do not seem to have been subjected to this iron staining, or to the quartz overgrowth. Pressure solution sutures along the contacts between quartz grains are common.

The pebbles, ranging in size from 4-10 mm, are moderately rounded to well rounded, found scattered throughout the member, and consist largely of quartz, chert, quartzite, jasper and shale rip-up clasts. These pebbles are commonly concentrated in single-layer stringers in the sandstone.

Argillaceous Deposits: Interbedded in the sandstones, and forming up to 30% of the assemblage locally, are beds of dark reddish grey, micaceous shale and siltstone up to 40



- | | |
|----------------------|-----------------------------|
| A = Quartzarenite | E = Arkose |
| B = Subarkose | F = Lithic Arkose |
| C = Sublitharenite | G = Feldspathic Litharenite |
| D = Lithic Subarkose | H = litharenite |

Fig. 3.37 Composition of Situndu Member sandstones

cm thick. One such bed, at the base of the Situndu Member near Mapumulo (Fig. 3.38), appears to have served as a source of rip-up clasts occurring a few metres away (Fig. 3.39).

3.1.4.4 Primary Sedimentary Structures: Bedding thickness generally varies between 0,3 and 1 m, but commonly exceeds 1 m. Where there is a rapid alternation of arenaceous and argillaceous beds, the bedding thickness is of the order of 10-30 cm. The beds are tabular, and planar cross-bedding is common. In the Kranskop area, trough cross-bedding is also common. In the planar cross-beds, the foresets are usually graded. Near Mapumulo, the bedding thickness can exceed 2 m, and there are tangential foresets marked by 5 cm-thick, white, mudstone drapes (Fig. 3.40).

3.1.5. DASSENHOEK MEMBER

3.1.5.1 General: The Dassenhoek Member is the youngest unit in the Durban Formation. It occurs from just north of Verulam and Wartburg in the north, to Hibberdene in the south, and from the coast in the east to the western margin of the basin. The name was proposed by Roberts (1981), from a locality to the southwest of Durban, which is also the type area. The Dassenhoek Member is the uppermost of the two resistant quartz-arenite units in the Durban Formation, and resembles the Kranskloof Member in colour, composition, sedimentary structures and outcrop expression, but is not as well developed in either thickness or distribution (Figs. 3.41; App-2.15). This member rests conformably on the Situndu Member and is conformably overlain by the Tulini Member. Where the Tulini Member is absent, the Dassenhoek Member is overlain paraconformably by the Newspaper Member of the Mariannhill Formation. (Fig. App-2.15).



Fig. 3.38 Shale lining (30 cm thick) to scour channel filled with sandstone, near Mapumulo

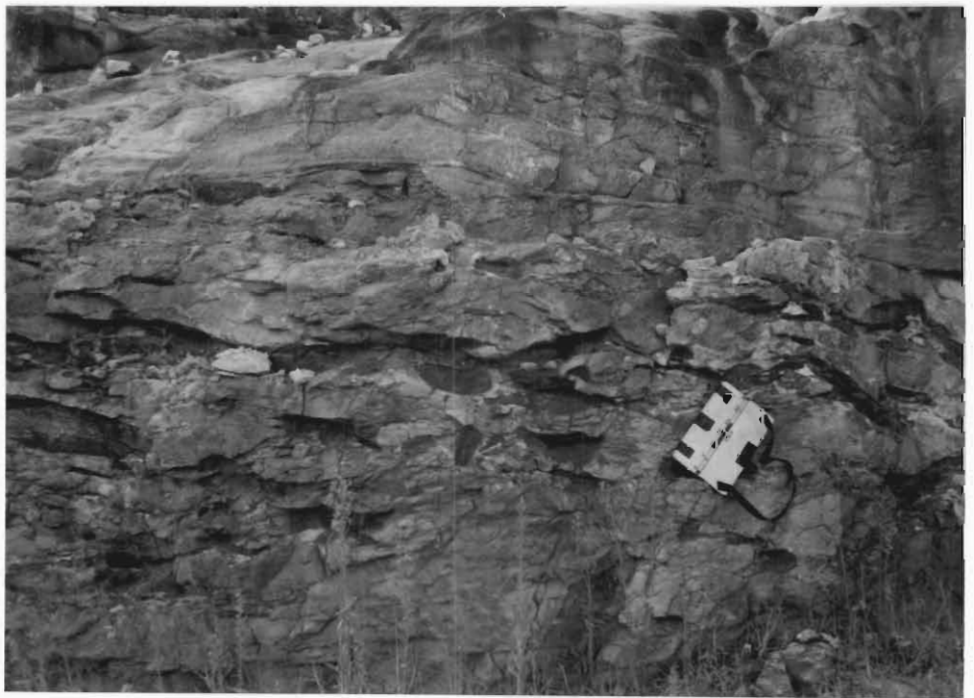


Fig. 3.39 Situndu Member with rip-up clasts probably derived from shale lining shown in Fig. 3.38, near Mapumulo



Fig. 3.40 White clay drapes on bedding and on foresets, Situndu Member, east of Mapumulo

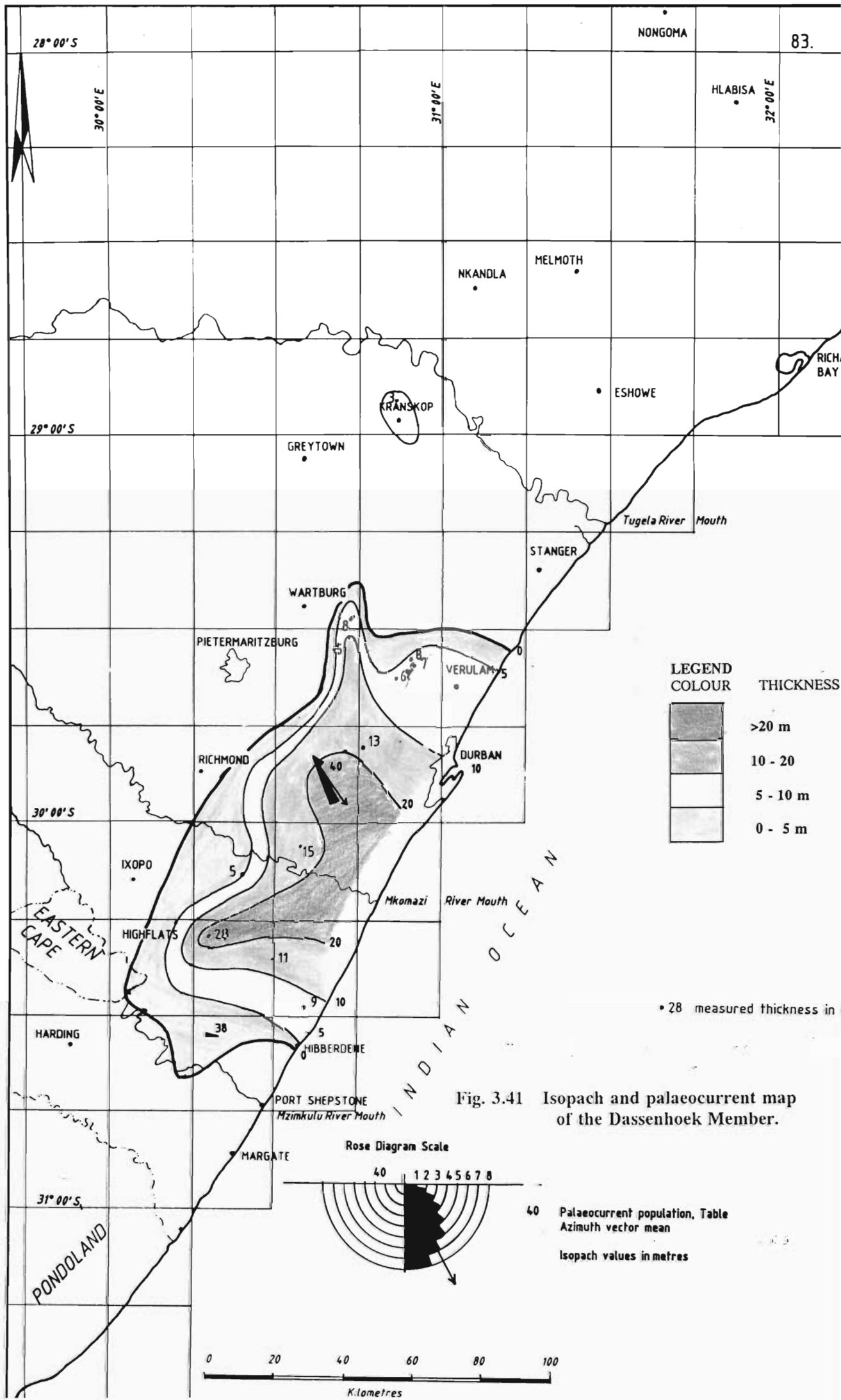


Fig. 3.41 Isopach and palaeocurrent map of the Dassenhoek Member.

3.1.5.2 Thickness: The thickness varies from 3-42 m, with an overall mean of 11 m. The mean thickness of the Dassenhoek Member increases from north to south, whereas the maximum thickness is developed in the vicinity of Durban (Table 3.5). The thickness at Tulini.

Wood Grange, at the very southern extremity, is about 7 m (Kingsley, 1975, Fig. 3).

Table 3.5 Thickness of the Dassenhoek Member (metres)

AREA	NUMBER	MEAN THICKNESS	MINIMUM	MAX.
MELMOTH	0	--	--	--
ESHOWE	0	--	--	--
KRANSKOP	3	5,3	3,0	8,0
DURBAN	8	12,5	5,0	42,0
SOUTHERN K'-NATAL	5	13,6	4,5	28,0
OVERALL	16	11,5	3,0	42,0

The isopach map (Fig. 3.41) indicates that the Dassenhoek Member sediments were deposited in a low relief depression, the known portion of which was roughly symmetrical about a WNW-ESE axis. The parallel tendency of the isopachs is due to the linear nature of the basin margin.

3.1.5.3 Lithology: The Dassenhoek Member consists very predominantly of sandstone, with subordinate interbedded shales and siltstones (Fig. App-1.26). The sandstone is silicified, medium- to coarse-grained, moderately-sorted and reddish grey. The silicification of the Dassenhoek Member is less well developed than in the Kranskloof Member, and consequently does not have as strong an outcrop expression as that unit. The composition

of the sandstones is largely quartz-arenite, but sub-arkoses also occur commonly (Fig. 3.42). Laminac with up to 4% heavy minerals, mainly opaque ores were reported by Roberts (1981).

3.1.5.3 Primary Sedimentary Structures

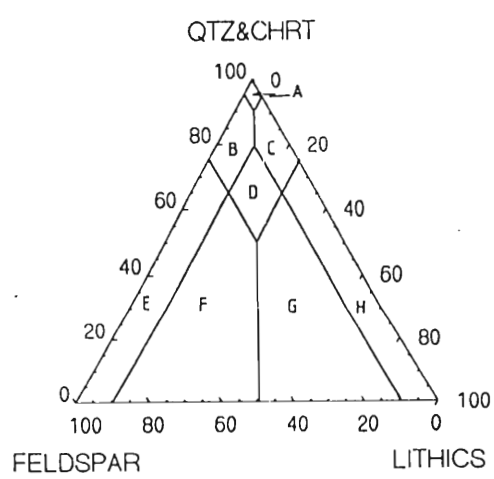
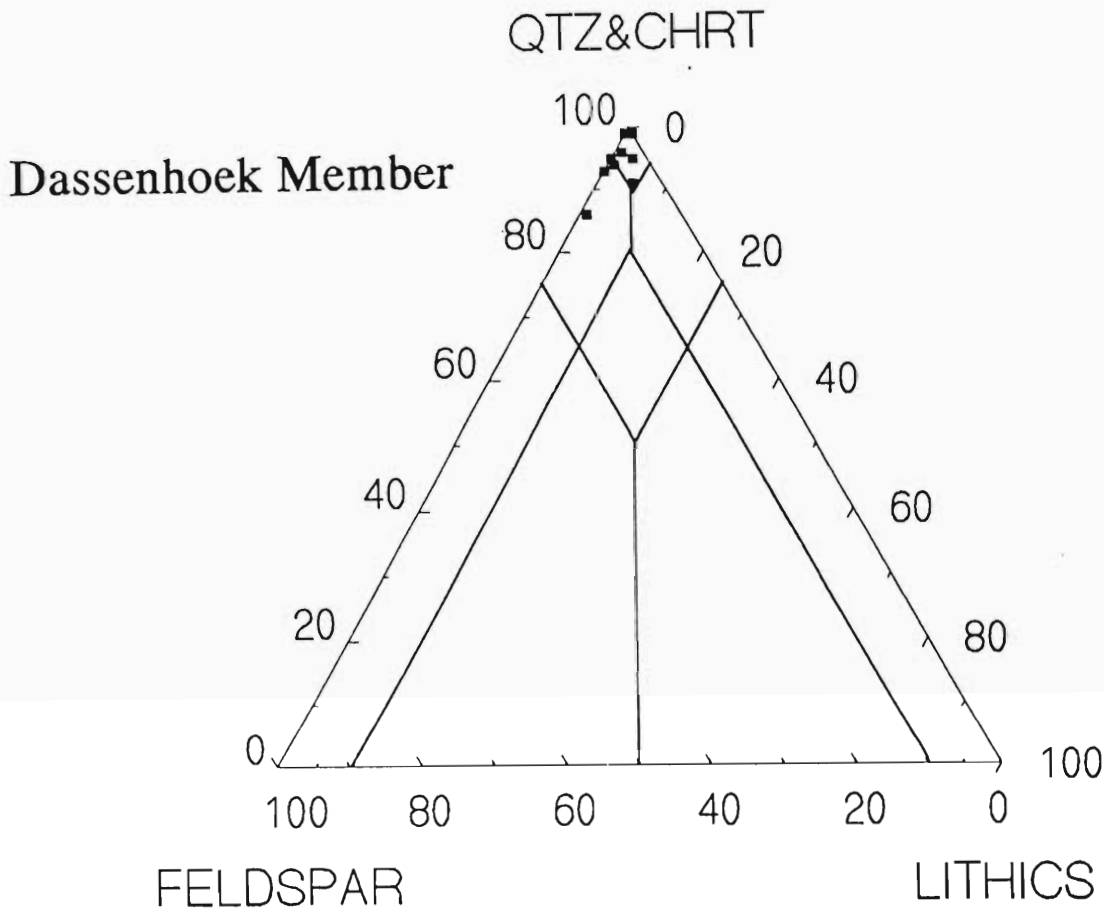
The dominant, though sparsely-developed, primary sedimentary structure in the basin north of Durban is planar cross-bedding, whereas south of Durban it is horizontal stratification.

3.2 MARIANHILL FORMATION

The Mariannahill Formation, is the younger of the two formations in the Natal Group. At the base is a conglomeratic unit. This is followed by a thick unit of arkosic sandstones and subordinate shales. The uppermost unit is a sporadically-developed conglomerate. The name Mariannahill was first suggested by Roberts (1981) from the area to the southwest of Durban where the Formation is well developed. It occurs throughout the Natal Group depositional basin.

3.2.1 TULINI MEMBER

3.2.1.1 General: The Tulini Member, which is the basal unit of the Mariannahill Formation, occurs over most of the northern portion of the basin as indicated in Fig. 3.43. The name Tulini was suggested by Marshall (1991a), and the type area lies between Kranskop and Wartburg (Fig. 3.43). This member is conglomeratic, and occurs as two geographically distinct facies, A and B respectively (Figs. 3.43; App-2.15). The basal contact of the Tulini



- | | |
|----------------------|-----------------------------|
| A = Quartzarenite | E = Arkose |
| B = Subarkose | F = Lithic Arkose |
| C = Sublitharenite | G = Feldspathic Litharenite |
| D = Lithic Subarkose | H = litharenite |

Fig. 3.42 Composition of Dassenhoek Member sandstones

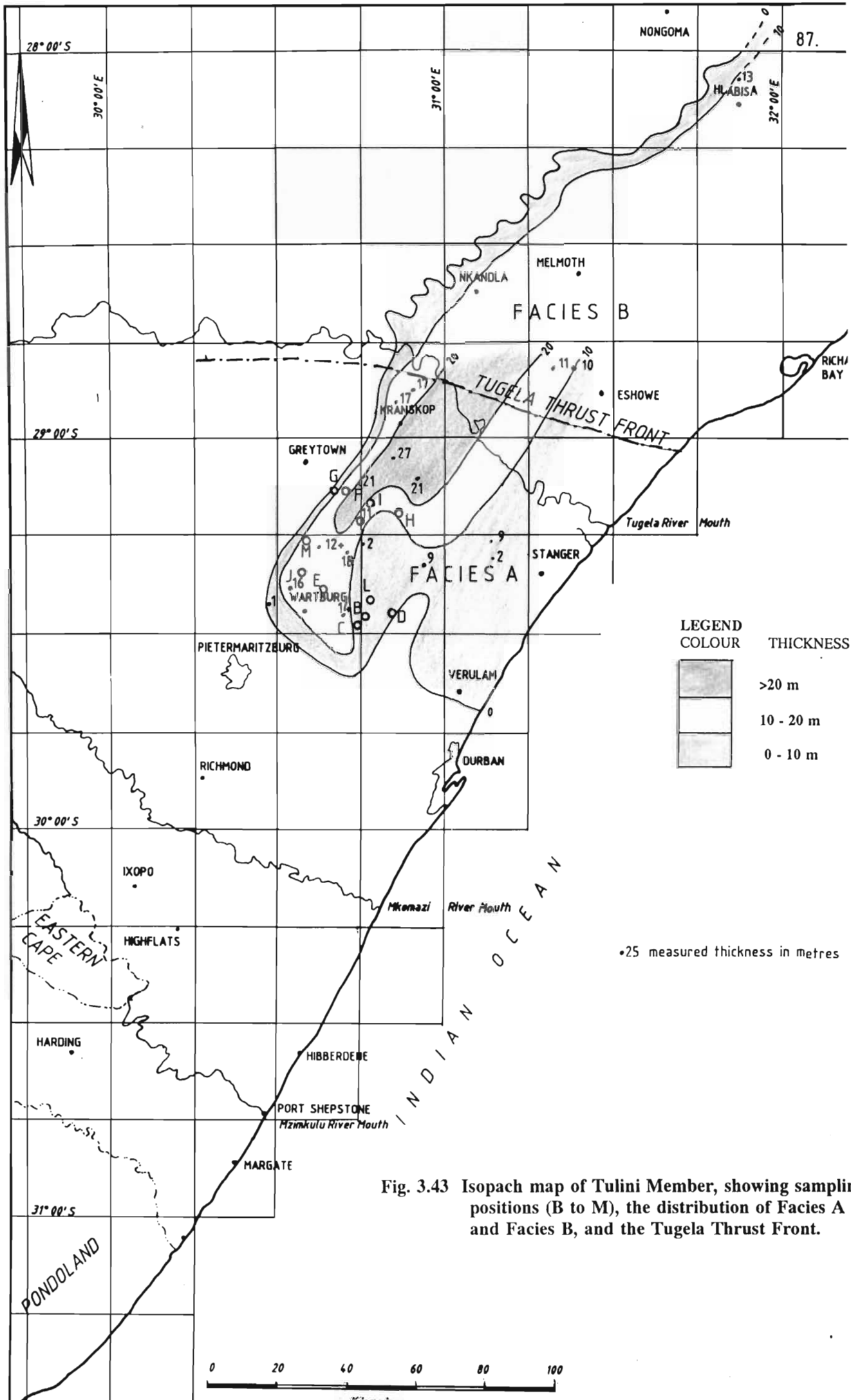


Fig. 3.43 Isopach map of Tullini Member, showing sampling positions (B to M), the distribution of Facies A and Facies B, and the Tugela Thrust Front.

Member is paraconformable. In the north it overlies the Eshowe Member directly, and southwards it progressively oversteps onto the Kranskloof, Situndu and Dassenhoek Members of the Durban Formation. This contact is sharp and erosional, and taken at the base of the lowest conglomerate. The upper boundary, with the Newspaper Member, is conformable, gradational to sharp, and defined as the horizon above which the conglomerate layers are either absent or constitute less than 5% of the rock.

3.2.1.2 Thickness

The thickness of this unit varies between 0,90 and 27,5 m, with a mean of 11,9 m (Table 3.6).

Table 3.6 Thickness of the Tulini Member (metres)

AREA	NUMBER OF SECTIONS MEASURED	MEAN THICKNESS	MINIMUM THICKNESS	MAXIMUM THICKNESS
MELMOTH	1	12,8	12,8	12,8
ESHOWE	4	7,9	2,0	10,5
KRANSKOP	15	13,1	0,9	27,5
DURBAN	0	--	--	--
SOUTHERN K'-NATAL	0	--	--	--
OVERALL	20	13,1	0,9	27,5

The isopach map (Fig. 3.43) reveals that there is a strong linearity to the isopach pattern, parallel to the present KwaZulu-Natal coastline, with the thickest portion close to the western margin.

3.2.1.3 Lithology - Facies A: This facies occurs in the type area, and consists of monomict (vein quartz), bimodal, clast-supported to matrix-supported, small-pebble

conglomerate with interbedded coarse-grained to very coarse-grained sandstone and granule-conglomerate, all sub-arkosic to arkosic. Visser (1974) claimed that vein quartz clasts are absent from the sandstones and conglomerates of the Natal Group in the Kranskop area, which is in the type area for Facies A, but the present study has proved otherwise. Dark reddish-grey micaceous shale also occurs. The conglomerate beds constitute approximately 50-55% of the unit, the arenaceous beds approximately 40-45%, and the argillaceous beds less than 5%. The colour of the rocks varies between pale red (5R 6/2) and greyish red (5R 4/2). Sorting is extremely poor. The matrix of the conglomerates is arenaceous, and consists of material virtually identical to the interbedded sandstone and granule-conglomerate.

Conglomerates: The mean bedding thickness of the conglomerates is 40 cm, with a maximum of 1 m. The beds are usually lenticular, with a lateral extent of between 5 and 25 m. The conglomerates are clast-supported to matrix-supported and are poorly sorted (Fig. 3.44).

Samples of at least 100 pebbles were taken at 12 different localities, and the long, intermediate and short axes measured. The results are summarised in Table App-5.1. and plotted in Figs. App-5.1 to App-5.13, falling predominantly in the fluvial field of Stratten (1974).

Clast Packing Density (CPD) (Kahn, 1956) varies between 50 and 70%. Clast Packing Proximity (CPP) (Kahn, 1956) varies between 40 and 60%. Mean maximum clast size (long axis dimension) is 66 mm, with a mean clast size (long axis dimension) of 25 mm.

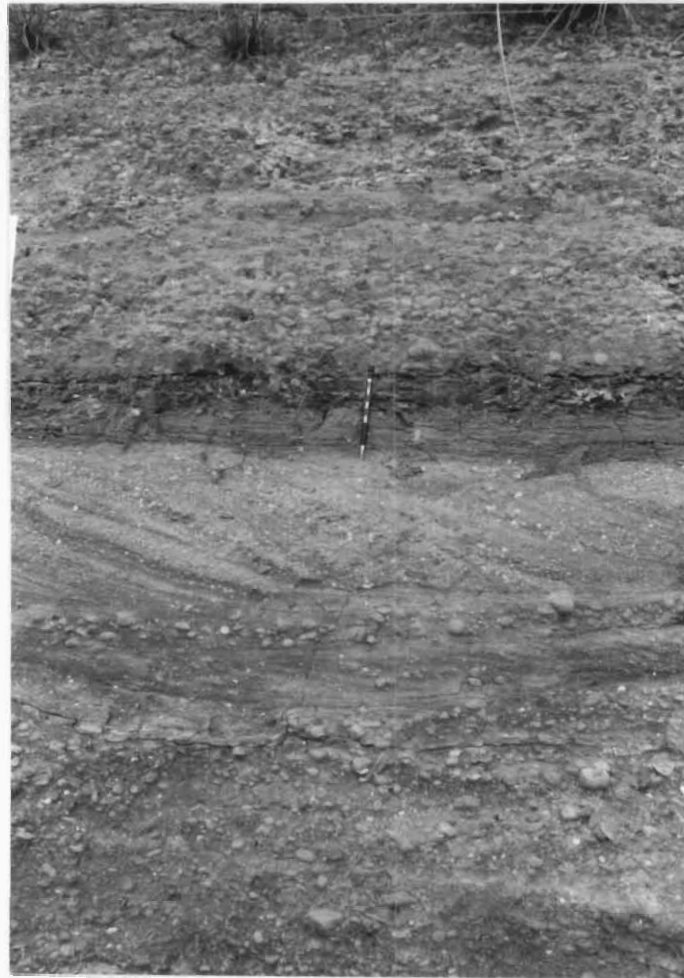


Fig. 3.44 Tulini Member clast- to matrix-supported pebble-conglomerate, south of Appelbosch

The means of the Flatness Coefficient, maximum projection sphericity, elongation coefficient, and the oblate/prolate index, are all remarkably constant (Fig. App-5.13; Table App-5.1).

Arenaceous Rocks: The mean thickness of the arenaceous beds is 40 cm, with a maximum of 1 m. The beds are commonly lenticular, and grade laterally and vertically into conglomerate. The arenaceous rocks are coarse-grained to very coarse-grained, sub-arkosic to arkosic, and locally micaceous. They are poorly sorted, with a granule content ranging between 10 and 60%. Dispersed throughout the arenaceous beds are phenoclasts of quartz, chert, quartzite and jasper. The colour of the arenaceous rocks is the same as that of the conglomerates, i.e. pale red (5R 6/2) to greyish red (5R 4/2), and the size range of the phenoclasts is the same as that of the clasts in the conglomerates.

Argillaceous Rocks: The beds of shale and siltstone are lenticular, with a mean thickness of 10 cm and a maximum of 50 cm. The lateral extent of the beds is of the order of 10 m. The shales are fissile, micaceous and greyish red (5R 4/2). They occur interbedded with the conglomerates and arenaceous beds.

3.2.1.4 Lithology - Facies B: Facies B occurs in the area indicated in Fig. 3.43, to the north of Facies A.

Conglomerate: The bed-thickness in Facies B is generally less than in Facies A, and the clasts are less well rounded and polymict (quartz, quartzite, chert, jasper and granite) (Fig. 3.45). The maximum clast size (long axis) determined was 30 cm, and the mean was 6 cm. The conglomerates are matrix supported, with a CPD of the order of 30%. The matrix is



Fig. 3.45 Facies B conglomerate, Tulini Member, north of Hlabisa.

an immature, poorly sorted, reddish grey (5R 4/2), coarse- to very coarse-grained, arkosic sandstone. Due to their greater hardness and banded nature, the jasper clasts are less well-rounded, and have a greater flatness coefficient than the other lithologies.

Arenaceous Rocks: The sandstones in Facies B are very similar to those in Facies A.

Argillaceous Rocks: There are no argillaceous rocks developed in Facies B.

3.2.1.5 Primary Sedimentary Structures: Scouring and planar cross-bedding are common features, the latter formed by currents directed to the south. Bedding is predominantly lenticular with a subordinate tabular component.

3.2.2 NEWSPAPER MEMBER

3.2.2.1 Introduction The Newspaper Member occurs from Hlabisa in the north to Hibberdene in the south, and from the KwaZulu-Natal coastline in the east to the western basin margin. As it is not resistant to weathering, and does not have a protective capping, erosion has caused the almost complete removal of this member from large areas of the basin. The name was suggested by the author (Chapter 2), and the type area is the area to the northeast of Appelsbosch. This unit, which consists of arkosic to sub-arkosic sandstones and interbedded argillites, is by far the thickest unit of the Natal Group, and forms the major portion of the Mariannahill Formation. It is everywhere characterised by the occurrence of calcite concretions, and south of Durban it is distinguished from the Durban Formation by the presence of soft-sediment deformation. The Newspaper Member rests conformably on the Tulini Member, and is overlain conformably by the Westville Member. At Nhlavini (Fig. 3.46) and downstream from the bridge over the Mtwalume



Fig. 3.46 Pale grey Newspaper Member sandstone at Nhlavini, NE of Ixopo. Note the horizontal stratification and soft-sediment deformation.

River on the old South Coast road the Newspaper Member lacks the ferruginous colouration, and the rocks are a dull grey in colour.

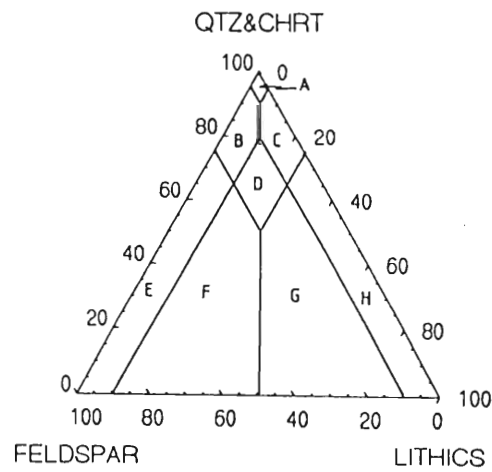
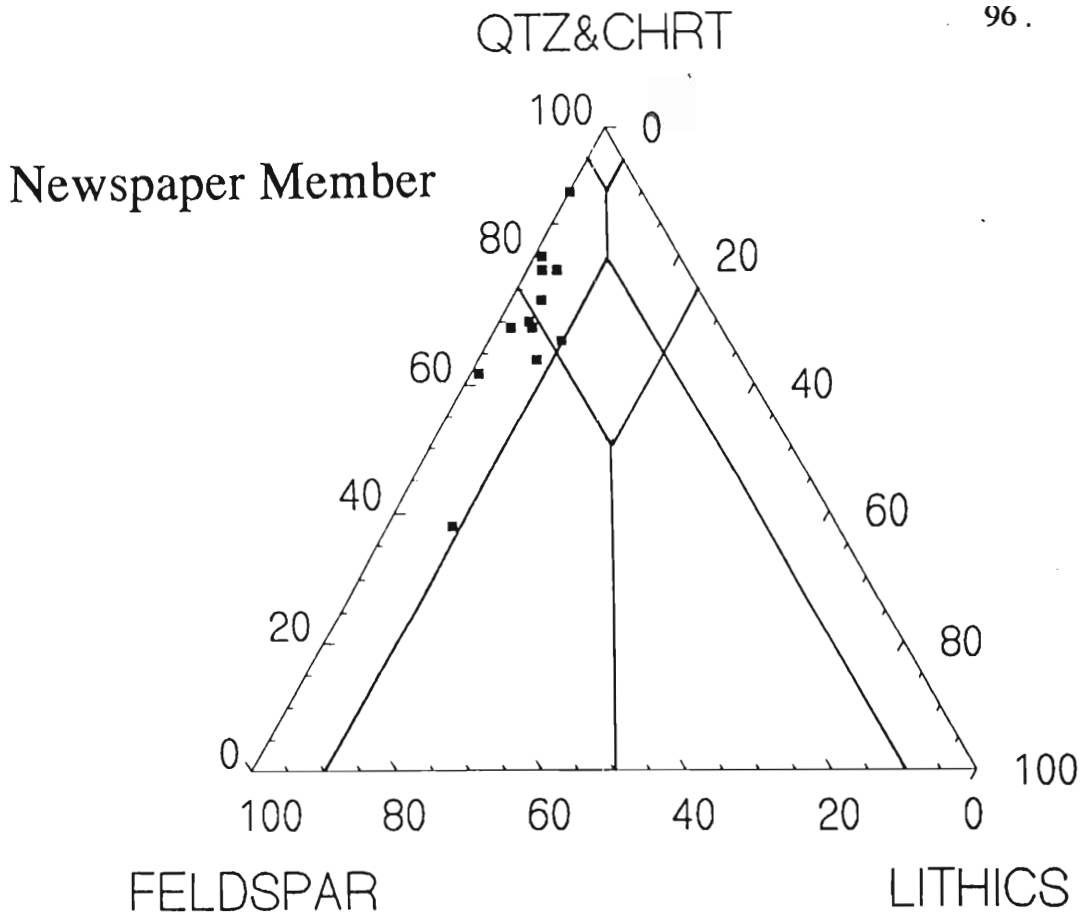
3.2.2.2 Thickness Only three complete sections were measured through this unit. These are situated near the edge of the depositional basin. The thicknesses recorded were 17,5 m, 22,5 m and 14,5 m. Nowhere else within the body of the depositional basin was it

possible to measure a complete section of this unit. A borehole drilled at Kloof passed through 430 m of Newspaper Member, but this is an incomplete section, with no stratigraphic top or base. The factors which make it virtually impossible to determine the thickness with any certainty are:

- a. weak outcrop expression,
- b. the prevalence of faulting,
- c. an indeterminable degree of erosion during the Dwyka glaciation as well as subaerial erosion during the long time interval between the cessation of deposition in the Ordovician, and the onset of Dwyka glaciation, and
- d. the lack of internal marker beds.

3.2.2.3 Lithology The Newspaper Member consists predominantly of greyish red (5R 4/2) to pale cream-coloured, medium-grained to very coarse-grained, poorly-sorted sandstones and granule-conglomerates.

Arenaceous Rocks: Compositions fall in the arkose and sub-arkose fields with up to 10% lithic content (Fig. 3.47). Scattered pebbles of chert, jasper, quartz and quartzite, up to 15 mm in diameter occur scattered throughout the arenaceous rocks, and are commonly



- | | |
|----------------------|-----------------------------|
| A = Quartzarenite | E = Arkose |
| B = Subarkose | F = Lithic Arkose |
| C = Sublitharenite | G = Feldspathic Litharenite |
| D = Lithic Subarkose | H = litharenite |

Fig. 3.47 Composition of Newspaper Member sandstones

concentrated as single-layer conglomerates. The grains are moderately rounded to sub-angular. A very common lithology in certain areas is a silicified, very coarse-grained arkose with a dark reddish colour derived from the red feldspars (See Fig. 3.20). Calcite concretions are commonly developed locally within the arenaceous sediments.

Argillaceous Rocks: Interbedded in the arenaceous rocks are siltstones and shales which are darker in colour than the arenaceous rocks, and invariably micaceous. The shales and siltstones are commonly lenticular in form, with thicknesses of the order of a few centimetres to 30 cm, and lateral extent of some tens of metres.

3.2.2.4 Primary Sedimentary Structures Bedding thicknesses are of the order of 30 cm to 100 cm. The most prevalent primary sedimentary structure is planar cross-bedding, commonly with graded foresets. This tends to occur in solitary sets, often with the sets exceeding 1 m in thickness. In the northern areas of the basin, trough cross-bedding is also very common. Ripple marks are very scarce. Horizontal stratification, with plane beds of approximately 10 mm to 20 mm occur. Scour channels are common throughout the basin (Fig. 3.48). Soft-sediment deformation is recognisable from the deformation it causes to primary sedimentary structures such as horizontal lamination and cross-bedding. Lourens (1979) identified a) slump structures (prelithification folds caused by horizontal mass movement of one or more beds), b) convolute lamination (crumpling or convolution of the laminae in a bed, recognised by remarkably continuous laminae which have sharp crests separated by broad troughs), c) overturned (recumbent) foresets (foreset laminae of ripples or megaripples which have been overturned in a down-current direction by drag caused by the sediment-laden currents flowing across the top of an unconsolidated cross-



Fig. 3.48 Large scour channel in Newspaper Member filled by planar cross-bedded sandstone, north of Hlabisa. Note small conglomerate lens marked by arrow. Stick is 1,5 m long.

bedded unit), d) air-heave and water-escape structures (see Fig. 3.29) - (small-scale, mainly vertical, structures which penetrate the otherwise undisturbed strata above), and e) mud diapirs (larger-scale structures in which the over-lying strata have been distorted by the mud layer which yields plastically under gravity differential adjustment).

Soft-sediment deformation will be discussed further in the section on the deposition of the Natal Group. Water-escape structures are common in the Newspaper Member.

3.2.3 WESTVILLE MEMBER

3.2.3.1 Introduction The Westville Member occurs very sporadically throughout the basin, but, south of Durban, was identified at only two localities. The name Westville was introduced by Roberts (1981) who first identified this conglomeratic unit at the top of the Natal Group succession. The type area is at Westville west of Durban. This member is characterised by being conglomeratic and at the top of the Mariannahill Formation. It rests conformably on the Newspaper Member, and is disconformably overlain by rocks of the Dwyka Group.

3.2.3.2 Thickness Because of the sporadic occurrence of this unit, and some uncertainty as to its boundaries, the writer was able, south of Durban, to determine the thickness (15 m) of the unit at only one locality, with any confidence. This was at Mgwahumbe, near Mid Illovo. However, three vertical sections were measured in the Melmoth/Hlabisa area, and thicknesses of 17 m, 9 m and 9 m were obtained. Roberts (1981) estimated the thickness of this unit to be of the order of 100 m, but, with the advantage of observations in the field, it is now felt that this is excessive, and that a thickness of between 10 m and

30 m is more realistic.

3.2.3.3 Lithology

Rudaceous and Arenaceous rocks: The Westville Member consists of reddish-grey to pale reddish grey, medium-grained to coarse-grained, lithic arenite (Roberts, 1981) to sub-arkosic and arkosic, sandstone to granule-conglomerate with scattered, well-rounded, clasts of quartz, chert, jasper and quartzite up to 5 cm in diameter, occurring throughout (Fig. 3.49). These clasts are commonly concentrated to form polymict, bimodal, matrix-supported to clast supported, small-pebble conglomerate. At Mgwahumbe, near Mid Illovo, the CPD was determined as 2% with a maximum clast diameter (long axis) of 90 mm. At Mntamntongayo, the maximum clast diameter (long axis) is 93 mm with a mean nominal diameter of 29 mm, mean sphericity of 70,3, and mean coefficient of flatness of 0,84. Single-layer pebble conglomerates are very common in this unit. Shape parameters determined on 202 pebbles from Mntamtanto, east of Eston, fall in the fluvial field of Stratten (1974) (Fig. 3.50). Rip-up clasts of dark greyish red shale (5R 4/2) are common.

Argillaceous Rocks Silty mudstone partings up to 5 cm in thickness, and interbedded shale beds, from 10-70 cm thick occur within the arenaceous rocks.

3.2.3.3 Primary Sedimentary Structures Arenaceous and conglomerate beds often attain a thickness of 1 m. Dominant planar and subsidiary trough cross-bedding are developed commonly. Soft-sediment deformation, predominantly slumping, is very common.

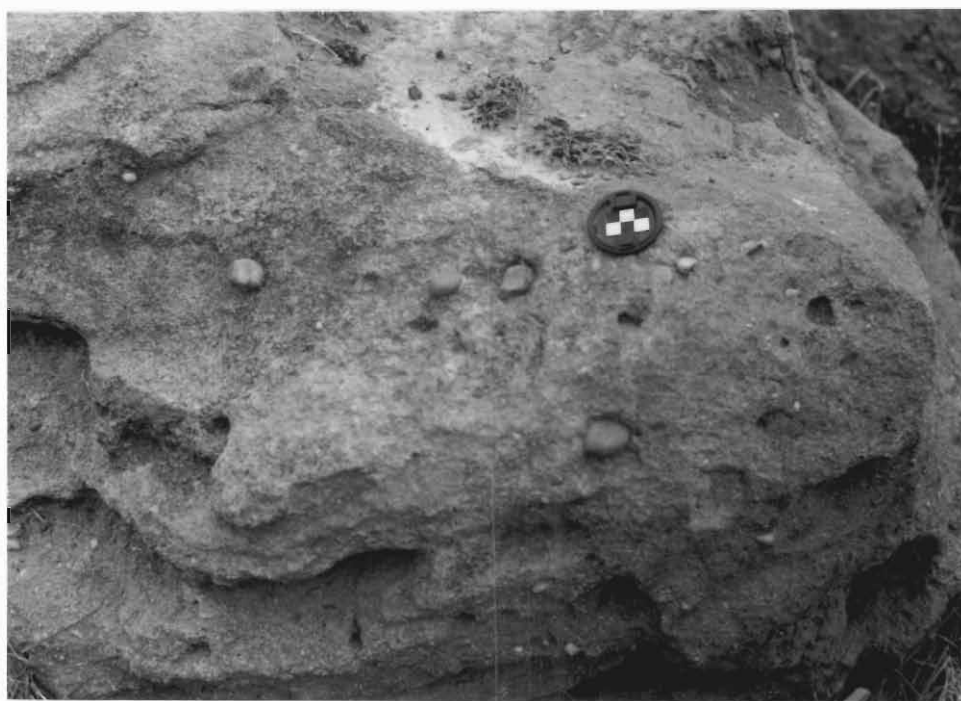


Fig. 3.49 Matrix-supported, polymict, pebble conglomerate, Westville Member, northeast of Melmoth.

Sampling Locality A

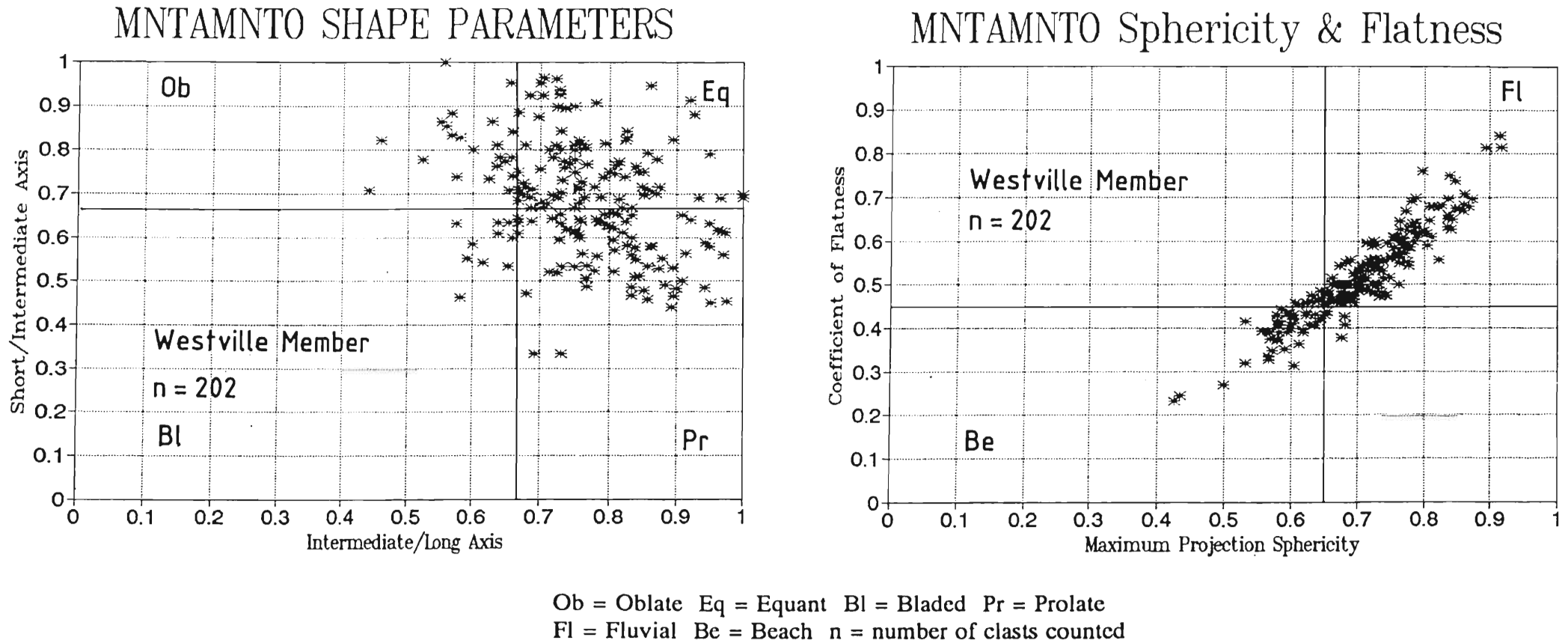


Fig. 3.63 Shape parameters and flatness vs sphericity, Mntamntanto Westville Member

4. CLAST MODIFICATION: NATAL GROUP THICKNESS

4.1 PRESSURE SOLUTION

One of the most remarkable features of the conglomerates of the Ulundi Member of the Durban Formation, is the presence of pressure solution pits and hollows on the surfaces of the clasts (Fig. 4.1). Tankard *et al.* (1982, p. 350) refer to these hollows as "abundant percussion marks". Trurnit (1968) asserted that pressure solution contacts originate below the groundwater table. The Thomson-Sorly-Riecke Principle operates between indurated clasts subjected to non-uniform or directed pressure in an environment of saturated solution. Under conditions of relatively high pressure, certain minerals are more subject to solution than others. He also determined that, in partners of equivalent relative-pressure solubility, the clast with the greater radius of curvature at the point of contact would be preferentially dissolved, and the clast with the smaller radius of curvature at the point of contact would thus penetrate some way into the other. This observation has been confirmed during the present investigation.

In most of the conglomerates of the Ulundi member, by far the greater majority of the contacts are smooth, with one clast being dissolved to form a hollow. The impinging clasts, which invariably had smaller radii of curvature at the points of contact, filled the hollows exactly and fully, and remained virtually unchanged (Fig. 4.1). In the type locality along the White Mfolozi River south of Ulundi, the conglomerates are monomict (quartzite), and matrix is scarce. It is thought that the pressure of the overlying Natal Group sediments was transmitted through clast-to-clast contact, as there would have been



Fig. 4.1 Ulundi Member quartzite clast (15 cm long) modified by pressure solution.

very little support from matrix. Because of the highly monomict nature of the conglomerates (Fig. 4.2), there was no compositional contrast and hence no relative pressure solubility gradient (see Trurnit, 1968) to determine which clasts would be preferentially dissolved, and which would remain virtually unaltered.

Thin-section investigation of the contacts between two clasts has revealed that none of the solution residue reported by Trurnit (1968) occurs in the Ulundi clasts. This is undoubtedly due simply to the fact that the quartzites are very pure, and there is virtually no feldspar or sericite to accumulate as the quartz is removed in solution. In areas of abundant matrix, where the pressure resulting from the load of the overlying rocks is thus more evenly distributed (such as Macala, just north of the Tugela River on the road between Jameson's Drift and Nkandla, Fig. 4.3), there has been no obvious pressure solution.

4.2 PRESSURE-FRACTURING

The initial result of directed pressure in areas of sparse matrix is the formation of pressure solution pits or hollows at the contacts between the clasts concerned. Where the pressure became extreme, because of very sparse matrix or a minimum of contact points to share the load, the clasts responded by fracturing. Also, where the strength of the clast was sufficiently reduced by the advanced development of pressure-solution hollows, fracturing of the so affected clasts resulted. The fragments have stayed largely in place, being confined by surrounding clasts, and have, in most cases, been welded together again by later silicification. Invariably, there is a pressure-solution pit at the focus of the pressure-induced fracturing (Fig. 4.4).



Fig. 4.2 Monomict nature, close-packing, pressure solution and fracturing, Ulundi Member conglomerate, south of Ulundi.



Fig. 4.3 Ulundi Member conglomerate with abundant matrix and no pressure solution phenomena. Macala, southeast of Dolwana



Fig. 4.4 Pressure solution followed by pressure fracturing of quartzite clast. Ulundi Member. South of Ulundi

4.2.1 INTERPRETATION

As the pressure which caused the fracturing in the clasts was the result of the burial by the overlying sediments, it was reasoned that an approximate minimum thickness of the overlying sediments could be ascertained from a knowledge of the strength of the fractured clasts. It is further submitted that once the overlying Natal Group sediments were indurated and consolidated, they would have borne the weight of the overlying Karoo Supergroup rocks, and their mass would not have been brought directly to bear on any irregularity such as the Ulundi Member conglomerate clasts. The glacial striae on the contact between the Natal Group rocks and the overlying Dwyka Group diamictites, and indurated clasts of Natal Group entrained within the Dwyka Group diamictites provide evidence of the induration of the Natal Group rocks prior to the commencement of the Dwyka glaciation. This latter observation was also reported by Roberts (1981) who further proposed that this provided evidence that the Natal Group was initially much thicker than measured at the present time. There is no evidence to substantiate or dispute Roberts' (1981) suggestion that strata equivalent to the upper Cape Supergroup were deposited over the Natal Group, and subsequently removed by erosion. Therefore it was reasoned that the mass of the Karoo Supergroup played no role in the pressure solution and fracturing of the Ulundi Member clasts.

The uniaxial compressive strength, in MPa, of sixteen clasts, all unweathered and unjointed, was determined (Table 4.1).

Table 4.1: Uniaxial Compressive Strength (UCS) in Mpa, derived from quartzite clasts of the Ulundi Member conglomerates.

SAMPLE	GAUGE READING	U.C.S. (MPa)
US-1 a	13,0	312,0
US-1 b	10,0	240,0
US-1 c	10,8	259,2
US-1 d	7,1	170,4
US-2 a	21,6	518,4
US-2 b	21,6	302,4
US-2 c	23,0	552,0
US-3 a	14,4	345,6
US-3 b	28,8	691,2
US-3 c	28,6	686,4
US-3 d	10,0	240,0
US-3 e	13,1	314,4
US-4 a	11,9	285,6
US-4 b	9,1	218,4
US-4 c	12,3	295,2
US-4 d	26,3	631,2
MEAN	15,78	378,9
STANDARD DEVIATION		174,8
MAXIMUM		691,2
MINIMUM		170,4

Dr. N. Richards of the Department of Geology, University of Natal, Durban has determined a point load strength (IS 50 values) of 9,6 MPa on one clast, which is equivalent to 9,6/0,8

= 12 MPa **tensile strength**, or 250 to 300 MPa UCS (N. Richards, pers. comm.²), which is similar to the value derived by the Silverton laboratory of the Geological Survey.

The strength of all but one of the quartzite clasts is "extremely strong", and that one clast fell into the "very strong" class (Bell, 1983, p. 508). It is maintained that the estimated thickness - as derived from the measured strength of clasts - would be a minimum thickness, as there is no means of determining the margin by which the mass of the overlying sediments exceeded the strength of the fractured clasts. Matthews (1988) derived a formula for estimating thickness of overburden from the strength of clasts. The formula is:

$$Z = (T \times (m-1)) / ((m-2) \times d \times g)$$

where Z = thickness of overburden in metres
 T = tensile strength in pascals (Pa)
 m = poisson number, suggested value of 4,85
 d = density of overburden suggested value of 2500 Kg/m³
 g = gravitational constant, suggested value of 9,81 m/sec²

Substituting in this formula we get :

$$378,9 \times 10^6 \times 3,85 / 8 / 2,85 / 2500 / 9,81 = 2608,8 \text{ say } 2600 \text{ m overburden.}$$

The figure 8 is a suggested possible conversion factor for UCS to tensile strength (F.G. Bell, pers. comm.³). Various authors use factors ranging between 8 and 24. If a mean factor of 16 were to be used, the calculated thickness would be 1304,4, say 1300 m. Some

² Dr N. Richards, Dept. of Geology, University of Natal, King George V Ave., Durban

³ Prof. F.G. Bell, Dept. of Geology, University of Natal, King George V Ave., Durban

caution should be used in applying this derivation (Matthews, pers. comm.⁴; Reddering, pers. comm.⁵) as the influence of the size and orientation of the point contacts is an almost indeterminable factor. Another factor is the sedimentary history (Reddering, pers. comm.). Where the matrix sand grains at Robberg (near Pletterberg Bay in the Western Cape Province) were deposited contemporaneously with the clasts, they lent support to the framework clasts, but where they were deposited later as a filter deposit, there was no added support, and the clasts were more easily fractured by the overlying mass.

4.2.2 CONCLUSION

The probable thickness of the Natal Group derived from the mass of the overburden which caused the fracturing of the clasts at the base of the Natal Group is of the order of 1300 to 2600 m. This is far in excess of the present occurrence, and would suggest that the upper limit of Natal Group sedimentation, prior to subaerial and possible glacial erosion, was considerably higher than the present top at the contact with the overlying Dwyka Group. This is discussed further, in the chapter on basin tectonics.

⁴ Prof. P.E. Matthews, Dept. of geology, University of Natal, Durban

⁵ Dr. J.S.V. Reddering, Council for Geoscience, Port Elizabeth

5. BASIN TECTONICS

5.1 INTRODUCTION

It would seem that the deposition of the Natal Group was tectonically controlled. The areas adjacent to, and outside of, this depositional basin do not have rocks of the same age. To the west, the Dwyka Group rocks rest directly on the basement, and to the south, rocks of the Cape Supergroup rest on the basement, with no evidence of Natal Group sedimentation in these areas. This chapter is devoted to the description of the Natal Group repository - its known and inferred limits and morphology, and the tectonics associated with the formation of the basin.

5.2 BASIN LIMITS

The known occurrence of the Natal Group deposits extends from Hlabisa in the north (Marshall, 1991a) to just south of Hibberdene in the south (Marshall *et al.* 1991; Thomas *et al.* 1992) (Figs. 1.1; App-2.15). Mapping during the present study has ascertained the western margin of the basin to be roughly parallel to, and some 60 to 70 km inland from, the present KwaZulu-Natal coastline, with reasonable confidence. Where the western margin is not faulted, the Natal Group is seen to thin very rapidly to the west (Fig. App-2.10). The eastern margin of the basin is unknown as the eastern portion of the basin was removed during the fragmentation of Gondwana. It is thought that the Mesozoic break-up of Gondwana occurred along the central axis of a trough which had an axial gradient to the south-southwest, leaving only the western flanks of the original basin on the southern

African sub-continent (Hobday and von Brunn, 1979). The known basin is truncated by the offshore Falkland-Agulhas fracture zone which runs very close to, and roughly parallel to, the present KwaZulu-Natal coastline. The Natal Group is known to occur below the seafloor, some 30 km offshore opposite Stanger, where borehole JC-1 was reported by du Toit and Leith (1974) to have intersected some 18 m of what they interpreted as Kranskloof Member. Corroborative evidence is provided by the trough - indicated on the isopach map of the Eshowe Member (Fig. 3.15) - the axis of which lies some 50 km from the western margin of the basin. If the Natal Group basin was symmetrical, and this trough lies at the centre, then the eastern edge of the basin would be approximately 40 to 50 km to the east of the present shoreline of KwaZulu-Natal.

The southern margin corresponds with the basement high of Kingsley (1975) and the Dweshula High (Thomas *et al.* 1992) (Fig. 1.1), over which the Dwyka Group lies directly on the granitic basement. The Dweshula High is coincident with a major Proterozoic basement suture - the Melville Shear (Thomas *et al.* 1991), The surface expression of this feature is approximately 60 km in length (E-W) by some 10 km in width (Fig 1.1). To the south of the Dweshula High, the Devonian (Lock, 1973) quartz arenites of the Msikaba Formation separate the basement from the overlying Dwyka Formation. At only two known localities do the Natal Group and Msikaba Formation rocks occur in juxtaposition.

Confidence in delimiting the northwestern and northern boundary of the Natal Group basin is afforded by the occurrence of coarse conglomerates of the Ulundi Member. These were deposited in intermontane river valleys (Matthews, 1961, 1970; Hobday and von Brunn, 1979; Marshall 1991a) and on associated fans, which are indicative of elevated basin

margins. This proposal is reinforced by the southeastward decrease in clast diameter and thickness of the unit from south of Babanango to northwest of Eshowe. Matthews (1970) suggested that the present north-western limit of the Natal Group represents the original basin margin. He based this assumption on a postulation that the Precambrian rocks with an elevated paleorelief to the north-west of this boundary probably represent the glacially modified north-western flank of the Natal Group depositional basin. He concluded that the contact between the Natal Group and the overlying Dwyka Group is more or less coincident with the upper limit of Natal Group sedimentation. The estimated minimum thickness for the Natal Group, before consolidation, of 2600 m (see Chap. 7) would argue against these conclusions. Even a thickness of 1300 m (half the estimate) would indicate a considerable amount of subaerial and possibly glacial erosion before deposition of the Dwyka Group.

As the Natal Group is seen to have been deposited in a fault-bounded basin (foreland graben or half-graben) the western lateral boundary was probably approximately where the present edge of the Natal Group is observed.

At the extreme northeastern limit of its known occurrence, 15 km north of Hlabisa (Figs. 1.1; 3.15; App-2.15), the Natal Group is approximately 200 m thick (Marshall, 1991a). Because the provenance of the Natal Group rocks is taken to be the Pan African mountains in southern Mozambique (discussed below), it is not unreasonable to assume that the northern margin of the Natal Group deposits could be considerably further to the north than the present outcrop. However, some caution should be exercised, as rapid thinning at the edge of the basin is known to occur. For example, in the Kranskop area near the known

western margin, the Natal Group thins from approximately 140 m to zero over a distance of only 8 km (Fig. App-2.10).

5.3 BASIN MORPHOLOGY

The palaeorelief of the floor of the Natal Group depositional basin varies quite considerably from rugged to subdued. It has been variously reported as summarised in Table 5.1.

Table 5.1 Previously-recorded palaeorelief (metres)

NAME	PALAEORELIEF	LOCALITY AND DESCRIPTION
Du Toit, 1931	240	Near Melmoth, with much subdued palaeotopography south of Melmoth
Gevers, 1963	30	Near Lilani Hot Springs
Rhodes and Leith, 1967	33 - 60	In the Mapumulo area, and a smooth undulating plain between Melmoth and Port St Johns
Tankard <i>et al.</i> 1982	300	Not specific as to locality

The prevalence of post-Natal Group tensional faulting in the basin makes an accurate regional assessment of the palaeotopography, using elevation above sea level, difficult, but the variation in thickness of the basal unit - the Eshowe Member - would give some indication of the order of the palaeorelief.

In comparison with the previously-reported palaeorelief figures (Table 5.1), there is an implied palaeorelief of the Precambrian floor of the basin, at the time of deposition of the Natal Group, of at least 500 m to 600 m in the Nkandla area. Near Ndindindi and Nomanci Ridges south of Nkandla, the Natal Group was deposited in pockets or local depressions in the irregular palaeosurface. The base of the Natal Group in this locality lies

at an elevation of 740 m a.m.s.l., whereas the tops of the neighbouring Nondweni Group quartzites lie at elevations of 1236 m, 1250 m and 1318 m, with no intervening faults (Fig. 5.1). The ruggedness of the topography in this area is probably due to its proximity to the western margin of the basin.

It would thus seem that the floor of the northern portion of the basin was characterised by rugged topography, whereas the southern portion, i.e. south of the Tugela Thrust Front (Matthews, 1972) and the Tugela Fault, the palaeofloor of the basin was gently undulating. The distinction between two palaeorelief patterns on the floor of the basin appears to be reflected in the distribution of several of the stratigraphic units of the Natal Group. Further, the distribution of the two facies of the Tulini Member also appears to be related to the boundary between the two regions (Fig. 3.43). The conglomeratic Ulundi Member is restricted to the high-relief northern portion of the basin, while the quartz-arenites of the Kranskloof and Dassenhoek Members are found only in the southern portion, where the palaeorelief was subdued.

The palaeosurface of the basin in which the Natal Group was deposited has a locally-preserved palaeoregolith which Hardie (1958, pages 16, 90) called "fossil soil", and which was overlain by a graded unconformity at the contact between the granitic basement and the overlying arenaceous rock of the Natal Group. This caused difficulty in determining the exact contact. He cited this as evidence of local derivation of the sediments which formed the Natal Group. The term "fossil soil" might be taken to imply an organic component, for which there is no evidence in the Natal Group, but the definitions of soil by Retallack *et al.* (1984) and Lakvulich (1969) would validate Hardie's use of the term,



Fig. 5.1 Ndindindi Ridge (Archaean quartzite) in background, south of Nkandla, showing high palaeorelief. Krans in middle foreground (centre of photograph) is Ulundi Member conglomerate overlain by Eshowe Member.

as allowance is made for the absence of land plants (Martini and Chesworth, 1992). Du Toit (1931) described deeply-weathered, tilted banded gneisses beneath the unconformable basal contact of the Natal Group in the Melmoth area. Rhodes and Leith (1967) reported that over the major part of the basin, there is no evidence of pre-Natal Group weathering of the palaeofloor rocks close to the contact with the Natal Group, and suggested that the weathered products would have been removed by erosion and deposited elsewhere during the initial stages of the deposition of the Natal Group. This was confirmed during the present study.

The isopach maps of the Eshowe and Situndu Members (Figs. 3.14, 3.36) reveal that there was a deep trough, open-ended to the northeast, and that the axis of the basin is approximately parallel to the present eastern seaboard of Zululand. Deepening of the basin from the lateral margin towards the central axis is much more rapid and pronounced in the north than it is in the south. This is taken as evidence that the northern portion of the basin was bounded by highlands to the northwest, whereas the southern portion, with its lower gradients, was a relatively slight depression on an open plain. There is no evidence as to the nature of the region neighbouring the eastern margin of the northern portion of the basin. However, the overwhelmingly northeast-to-southwest palaeocurrent direction within the Eshowe Member (See Fig. App-4.1 discussed in Appendix 4), would indicate a highland in that area.

5.4 TECTONICS

5.4.1 REPOSITORY

5.4.1.1 Names, Shape, Boundaries, Origin: The presently-known occurrences of the Natal Group, the Msikaba Formation, and the position of Mozambique, are shown on Fig. 1.2. For the sediments which now form the Natal Group to accumulate, a repository was necessary. Ryan (1967, p.155) identified a "Natal Trough" which had an axis trending approximately parallel to the present KwaZulu-Natal coastline, and plunging to the south-southwest. He suggested that the western margin of the Natal Trough is approximately the same as the western margin of the present occurrences of the Natal Group (see new map of Natal Group occurrence). He also proposed that this Natal Trough was bounded on the east by a strongly positive tectonic element which was expressed as eastern highlands and which extended southwards from southeastern Mozambique for a distance of some 800 km, and was probably situated about 160 km to the east of the present KwaZulu-Natal coastline. Ryan further contended that the linear downwarp (the Natal Trough) conformed to the structural and sedimentological constraints of a yoked basin, which he defined (p. 155) as "a subsiding linear basin on the cratonic platform and lying adjacent to a complimentary uplift which supplies the sedimentary detritus". This definition agrees essentially with that of a zeugogeosyncline (synonym of yoked basin) of Gary *et al.* (1972).

The existence of the Natal Trough prior to Karoo times was assumed by Winter and Venter (1970). They described the extension, into KwaZulu-Natal, of the Table Mountain Series, and suggested that this provided evidence for the position of a depositional trough - the

Natal Trough, much of which now lies beneath the Indian Ocean. Stratten (1974) submitted that the western margin of the Natal Trough was situated along a hinge-line located near the western edge of the Dwyka outcrop belt in KwaZulu-Natal. All the isopach maps prepared during the present study indicate an elongate (NE-SW) trough, and the palaeocurrent direction (NE-SW) would substantiate the proposal a trough with an axial gradient to the south-southwest as a receptacle for the Natal Group sediments (see Matthews, 1970). Visser (1974) divided the Table Mountain Group into three facies, viz. the Cape, Pondoland and Natal Facies. The last of these was deposited in the "Natal Embayment", and differed from the Pondoland Facies in being a red-bed facies, grading southwards into the pale grey Pondoland quartz arenite facies. He invoked the Natal Embayment as the northeastern extremity of the Cape Basin, and cited the change in lithology of the Table Mountain Group towards the northeast as substantiating evidence.

Hobday and von Brunn (1979) described the Natal Embayment as having an axial gradient from a rugged provenance area in the northeast towards the open ocean in the southwest. In attributing the Natal Embayment to a failed rift, Hobday and von Brunn (1979) implied a zone of structural weakness that underwent early Palaeozoic crustal attenuation and rift subsidence which aborted prior to the Mesozoic fragmentation of Gondwana. P.E. Matthews (pers. comm. ⁶) rejected the idea of a failed rift on the grounds that there are none of the expected growth faults that normally accompany failed rifts, and preferred to consider the existence of a half-graben. The rugged palaeotopography in the north ceased at approximately the locality of the Tugela Fault (du Toit, 1931). The rapid thinning of the Natal Group along the western margin of the basin (Marshall, 1991b; 1991c), the

⁶Prof. P.E. Matthews, University of Natal, King George V Ave., Durban.

evidence of the trough shape as deduced from the isopachs (Fig. 3.15), the existence of pre-Natal Group palaeokranses at, e.g. Loliwe (Fig. 3.13b), and the prevalence of faulting in the vicinity of the western margin of the basin (Marshall, 1991b; 1991c) would thus reinforce the contention that the Natal Group depositional basin was a foreland graben. Tankard *et al.* (1982) held that the rift proposed by Hobday and von Brunn (1979) was reactivated in Dwyka times and again in Ecca times, thus proposing continued activity which culminated in the disruption of Gondwana.

5.4.1.2 Basins and Terrains: Rust (1975), in discussing the tectonic and sedimentary framework of Gondwana basins in southern Africa, suggested that the Palaeozoic to Mesozoic rocks were deposited in separate basins which he termed the Karoo and Zambezi tectono-sedimentary terrains respectively. The Zambezi Terrain is a series of individual yoked fault basins which seem to have come into existence as partly interconnected downwarped basins, whereas the Karoo Terrain is a cratonic area of basins and swells on a stable shelf area. He showed the southwestern boundary of the Zambezi Terrain skirting the northern boundaries of South Africa and Swaziland and passing into the Indian Ocean in northern KwaZulu-Natal (Rust, 1975, Fig. 38.1), with the qualification that it is ill-defined. The main distinguishing feature of the Zambezi Terrain is its tensional fault tectonics, which is also a feature of the Natal Group depositional basin. The western margin of the Natal Group depositional basin, which is marked by a zone of faulting (Marshall, 1991b, 1991c) coincides approximately with the boundary between Karoo and Zambezi Terrains as modified by Thomas *et al.* (1993).

5.4.1.3 Provenance: If the Natal Group sedimentary rocks were derived from an eastern

orogenic belt, as suggested by Ryan (1967), then they should be molasse deposits. Whitten and Brooks (1972, p. 296) defined molasse deposits as: "sediments produced by the erosion of mountain ranges at the final phase of an orogeny. these post-tectonic sediments include arkoses, polymict conglomerates and breccias and reddish-brown shales. They appear to have developed in intermontane areas, which are commonly non-marine."

Pettijohn (1975) drew attention to the fact that some molasse deposits have conspicuous sequences of red sandstone and mudstone, and that the red colour indicates oxidation and desiccation, and hence deposition under subaerial conditions. Both of these descriptions are compatible with the rocks of the Natal Group. Thomas *et al.* (1993) have identified the Natal Group depositional basin (Natal Trough of Ryan 1967, Natal Embayment of Visser, 1974) as a foreland graben, into which the Natal Group sediments, now recognised as molasse (Thomas *et al.* 1992, 1993), were deposited. The molasse was shed off a Pan African orogenic belt to the north and northeast - possibly in what is now Mozambique (Thomas *et al.* 1993). The palaeocurrent directions (see chapter 6) indicate very strongly that the provenance of most of the Natal Group sediments was to the north and northeast of the exposed portion of the depositional basin. For deposition to have taken place in the early Ordovician (490 Ma, Thomas *et al.* 1992), there must have been prior uplift in the provenance area, probably in Pan African times. The presence of an uplifted area to the northeast, which could have provided the sediments deposited in the foreland graben of the Natal Group depositional basin, as suggested by Ryan (1967), is supported by Thomas *et al.* (1992, 1993; Pinna *et al.* 1993).

Tankard *et al.* (1982) stated that the Mozambique Structural Province underwent Pan

African basement reworking in the late Proterozoic and early Palaeozoic, but that there are no syntectonic deposits, implying that there was no mountain-building during this event. However, Pinna *et al.* (1993) claimed that there was a Pan African mountain-building event in Mozambique. Recent Gondwana reconstructions (e.g. Martin and Hartnady, 1986) show that Western Dronning Maud Land in Antarctica was situated close to KwaZulu-Natal. In this area, a deformation and cooling age of ~500 Ma has been widely reported (e.g. Jacobs, 1991), implying a major early Palaeozoic orogenic episode in this region. This could have provided a source for the largely molasse deposits of the Natal Group. Thomas *et al.* (1992) reported on detrital muscovites with an age of ~580 Ma and secondary clay fractions with an extrapolated age of ~490 Ma in samples taken from the Natal Group in southern KwaZulu-Natal. There is no evidence of a high-temperature Pan African overprint recorded for the basement rocks of KwaZulu-Natal (Thomas *et al.* 1992), and therefore the ~580 Ma detrital muscovite must have been derived from a source outside the basin - ideally an elevated area with a Pan African signature - situated probably in southern Mozambique as indicated by the palaeocurrent data (see Appendix 4.).

5.4.1.4 Contemporaneous and Continued Downwarping: Turner and Whateley (1983) maintained that the forces which caused the fragmentation of Gondwana were initiated some 450 million years ago, coinciding with the tectono-thermal event of the Mozambique Mobile Belt, and suggested that narrow, linear pre-fragmentation grabens were active in pre-Karoo times. These structures, one of which was the Nongoma Graben, significantly influenced the sedimentation in the area. Bott (1976) stated that passive continental margins are often occupied by narrow, linear, graben-like sedimentary basins just prior to fragmentation. The prolonged activity of the Natal Trough, at least into Permo-

Carboniferous times, is implied by Matthews (1970) who pointed out that the ice-flow directions within the basin were governed by the subsidence of the Natal Trough. In Fig. 5.2 the ice-flow direction is clearly the same as the palaeocurrent direction as shown by the trough cross-bedding. This continued activity of the Natal Trough is also attested to by von Brunn (1994), who demonstrated that continued subsidence of the trough influenced the style of the Dwyka sedimentation. Also, Cairncross (1989) referred to subsidence in the eastern Natal coalfield. Van Vuuren and Cole (1979) appealed to continued activity of the Natal Trough as an influence on the deposition of the Vryheid Formation in the eastern KwaZulu-Natal coalfield. Further, Turner and Whateley (1983) inferred that the thickening of the coal measures in the Nongoma Graben was due to further activity within the Natal Trough. The deep trough indicated on the Eshowe Member isopach map (Fig. 3.15) could possibly represent a further graben structure within the depositional basin, similar to the Nongoma Graben.

The minimum sediment cover, calculated from the strength of the quartzite clasts, is of the order of 2600 m (see Appendix 3.). This thickness of sediments must thus have been deposited rapidly, and made possible by rapid subsidence of the basin floor. Once the Natal Group sediments were consolidated, they would have attained strength, and the mass of any overlying rocks, such as the Karoo Supergroup, would not have been transmitted directly onto the clasts to fracture them. Therefore the fracturing was not caused by the added burden of the Karoo cover, but by the mass of the unconsolidated Natal Group sediments themselves.

5.4.1.5 Contemporaneous Volcanism: Tankard *et al.* (1982) submitted that the



Fig. 5.2 Glaciated pavement on Kranskloof Member at Ifume, Natal South Coast. Ice-flow direction coincides with trough cross-bedding axis in foreground. (Photo by V. von Brunn)

contemporaneous downwarping of the Natal Embayment was accompanied by seismic tremors which triggered the slump structures in the Natal Group sediments reported by Matthews (1961), by causing instantaneous liquefaction. The abundant dewatering structures are consistent with contemporaneous earthquake activity, as is the evidence of contemporaneous volcanism found in the lower part of the Natal Group (Marshall *et al.* 1991; Thomas *et al.* 1992). This would argue against the contention of P.E. Matthews (pers. comm.⁷) that there were no growth faults formed during the deposition of the Natal Group.

At 571 ± 57 Ma (R.J. Thomas, 1994, pers. comm.⁸), the basement on which the Natal Group sediments were deposited lay at a depth of ~8 km (~250°C) below the surface, as shown by sphene fission track data (Jacobs and Thomas, 1994). This thickness may have been caused by the presence of westward-directed overriding nappes which resulted from the Pan African orogenic event which took place to the east, in present-day Mozambique, the Falklands, or Western Dronning Maud Land in Antarctica. During subsequent uplift and erosion between ~570 and 490 Ma, the ~8 km of material which was removed, must have been deposited elsewhere, probably to the south and southeast, along with the material from the Mozambique Pan African mountains which would have been eroded contemporaneously with the ~8 km of basement, as no depositional basin existed where KwaZulu-Natal is now situated.

Shortly before the commencement of the Natal Group deposition, the depositional basin

⁷ Prof. P.E. Matthews, University of Natal, King George V Ave., Durban

⁸ Dr R.J. Thomas, Council for Geoscience, P.O. Box 900, Pietermaritzburg

was initiated by the formation of a foreland graben, probably related to the Pan African collisional event, and it was into this receptacle that the molasse was deposited. The formation of the foreland graben was apparently accompanied by volcanic activity, as evidenced by the tuffaceous beds within the Natal Group (Thomas *et al.* 1992). Subsidence of the Natal Group basin continued, to accommodate the large amount of material being shed off the Pan African mountains in Mozambique, until the estimated total thickness was ~2600 m. In the interim period of probably 100 Ma or more, between cessation of Natal Group sedimentation and commencement of Dwyka Group sedimentation, subaerial erosion took place to reduce the thickness of Natal Group sediments to approximately the present situation

6. DEPOSITION

6.1 INTRODUCTION

Without a suitable receptacle, appreciable amounts of sediments will not be preserved in the stratigraphic record. It has been established that the repository for the Natal Group was a foreland graben, parallel to the present coastline of KwaZulu-Natal, and with an axial gradient to the south-southwest (Chapter 5; Matthews, 1970; Thomas *et al.* 1993). Hardie (1958), Mathew (1971), Hobday and von Brunn (1979), Rhodes and Leith (1967), Kingsley (1975) and others stated that the rocks of the Natal Group, apart from the quartz arenites, were deposited in a fluvial environment. Modern fluvial environments cannot be directly compared with vegetation-free pre-Devonian fluvial sedimentation (Fuller, 1985). However, the remarkably consistent palaeocurrent direction, the common occurrence of scour-channels and the marked lateral and vertical variation in lithofacies, would strongly suggest that depositional environment for the Natal Group was fluvial. Of the nine alluvial basin-fill models defined by Miall (1981a), his model 6, with longitudinal trunk drainage, transverse proximal fan/river and a medial longitudinal river, most closely complies with the requirements for the Natal Group. Miall (1981a) identified four parts to an alluvial drainage system. These comprise a) headwaters in upland source areas, b) proximal environment immediately below the fall line, c) medial environment and d) distal environment where the rivers interact with some terminating environment such as a lake or the sea. From the current study, it would appear that the distal portion is missing from the known basin, as no evidence of any such terminating environment has been identified. This is presumably because the distal part was situated to the southeast of the present

KwaZulu-Natal coastline. The basin-fill material now accessible would thus represent the proximal and medial zones, with some from the headwaters zone.

An alluvial fan is a "low, outspread, relatively flat to gently sloping mass of loose rock material, shaped like an open fan or a segment of a cone, deposited by a stream (esp. in a semi-arid region) where it issues from a narrow mountain valley upon a plain or broad valley....." (Gary *et al.* 1972). It was reasoned, therefore, that the identification of fan deposits could be used as an indicator of sharp basin-margin relief, probably fault-controlled. From the presence of rock-avalanches and debris-flows (Chapter 3; Blair and Mc Pherson, 1994), it can be postulated that alluvial fans were common along the fault-line-scarp bounded western margin of the basin.

Rhodes and Leith (1967) attributed the origin of the Natal Group to fluvial deposition on coalescing floodplains and alluvial fans with marshy lakes. As there was no terrestrial vegetation present in the early Palaeozoic (Fuller, 1985), these inferred marshy lakes would better be termed partially inundated mud-flats. Rhodes and Leith (1967) further proposed that the Natal Group rocks are a purely terrestrial, red-bed succession, the deposition of which was interrupted by periods of marine inundation as a southern sea transgressed northwards from what is now Pondoland as far as where the Tugela River is situated today. Roberts (1981), Visser (1974), Kingsley (1975), Hobday and von Brunn (1979), and others, have ascribed the Natal Group to a fluvial environment, braided or unspecified.

Miall (1978) described six braided river types, two of which appear to be of particular relevance in the discussion of the deposition of the Natal Group arenaceous rocks.

The first is the Platte Type, whose characteristics are:

- a) broad and shallow;
- b) no defined topographic difference between active and inactive areas;
- c) dominant linguoid or transverse sandy foreset bars, giving rise to superimposed sets of lithofacies Sp (The lithofacies listed are explained in Table App-1.3);
- d) Lithofacies St is scarce, reflecting the rarity of deep channels;
- e) lithofacies Sr, Sh, Fl, Fm may occur; and
- f) few cycles are developed.

The second is the Bijou Creek Type, whose characteristics are:

- g) Upper flow regime conditions sand moulded into plane-beds (Sh lithofacies);
- h) Parting or streaming lineation often developed in the Sh lithofacies;
- i) This exceptionally high flow energy is rare in perennial streams, but common in ephemeral rivers which are characterised by infrequent, violent flash-floods in which the flow may be channelised or occur as sheet flood;
- j) Facies models for ephemeral rivers all emphasize the importance of Sh lithofacies in the sedimentary assemblage (Miall, 1977);
- k) Lithofacies Sp, Sr, Fl, and Fm may be produced during waning flood stages.
- l) Thicknesses of more than 1,5 m may be deposited during one flood event, because of the high energy and competence; and
- m) Erosional surfaces with intraclasts (lithofacies Se) and low-angle cross-beds filling scours (Sl) may also be important.

Roberts (1981) has suggested that the rivers which deposited the Natal Group (apart from

the supposedly shallow marine quartz-arenites) were transitional between the Platte and Saskatchewan Types of Miall (1978). From the current basin-wide investigation of the Natal Group, it would seem, however, that rivers of both Platte and Bijou Creek Types, as well as transitional between them, were dominant, as the features described by Miall (1978) above were commonly encountered. Smith (1970) maintained that superimposed transverse bars - as evidenced by planar cross-bedding common in the Natal Group rocks - is evidence of a rapid increase in the depth of the stream depositing the sediments, concomitant with flash-flooding.

6.2 SEQUENCE OF EVENTS

6.2.1 DEVELOPMENT OF BASIN

The initial stage in the late Proterozoic or early Palaeozoic establishment of the repository for the Natal Group sediments commenced with the formation of a foreland graben or half-graben in the foreland which consisted of craton and Natal Metamorphic Belt. This was divided by a plane of weakness which would later manifest as the Tugela Fault (Fig. 6.1a; Chapter 5). As the eastern portion of the basin is missing (see Chapter 5), only a half-graben is illustrated. Subaerial erosion reduced the sharp relief (Fig. 6.1b). The axial gradient of the Natal Trough was to the south-southwest (Matthews, 1970), and was presumably fairly steep with a prevalent erosional regime, as there is no record of any sedimentation having taken place at this stage. The next step was the development of the Tugela Fault, which relatively elevated the northern, cratonic block (Fig. 6.1c). This elevation of the cratonic section would have caused rejuvenation of the drainage, and

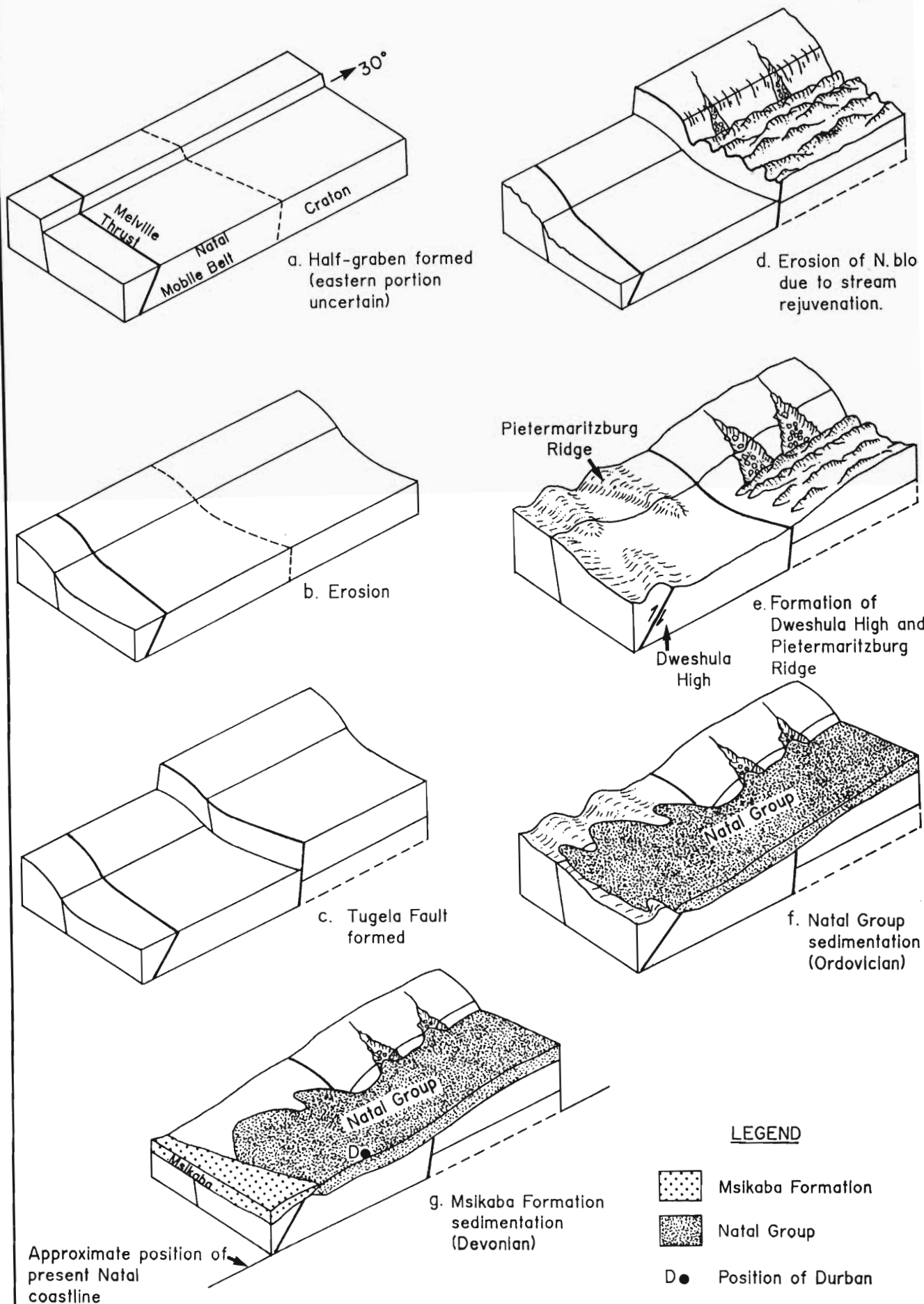


Fig. 6.1 Sequence of events in the Natal Group depositional basin

consequent accelerated fluvial erosion of the floor of the graben portion and its flanks (Fig. 6.1d). The pronounced palaeorelief of the basin floor to the north of the Tugela Fault is corroborative evidence of this.

Alluvial fans are almost certain to have formed at the foot of the Tugela Fault scarp, but no evidence of such has been observed. It can only be presumed that any such conglomeratic deposits have been removed by erosion, and transported southwards to be deposited beyond the presently known portion of the basin. The elevation of the cratonic section of the basin would have assisted in the removal of some 8 km of basement material as discussed in Chapter 5. The formation of an elevated highland - the Pan African orogenic event - in southern Mozambique (see Chapter 5.) at about the same time would have provided much sediment for the high energy rivers to transport into the Natal Group depositional basin. None of this is evident, however, and it would seem that the present basin, at that stage, was still in an entirely erosional regime, and all the sediment, derived from both the Pan African mountains, and the Natal Trough itself, was transported beyond the position of the present coastline of KwaZulu-Natal to be deposited elsewhere. It is possible that these sediments were laid down in the Cape Supergroup basin to the south.

6.2.2 EARLIEST DEPOSITS

The formation of fault-line scarps along the western margin of the Natal Trough, would have allowed the generation of talus deposits such as observed at Loliwe (see Chapter 3.). It is suggested that the Loliwe palaeotalus resulted largely from a catastrophic collapse of a Mozaan Group quartzite kran, rather than from gradual accumulation as a result of

toppling of blocks during gradual retreat of the kranes. The deposit would thus be classified as a rock avalanche, as defined by Blair and Mc Pherson (1994). The interstitial material appears to be identical to the Eshowe Member shale which overlies the deposit (description of Loliwe deposit, Marshall, 1991a), but with the addition of sand-sized particles and granules. The matrix probably infiltrated the palaeotalus, filling the voids, as the Eshowe Member sediments were deposited. Tanner and Hubert (1991) stated that the presence of horizontal or inclined gravel layers within the matrix of a conglomerate is consistent with progressive infiltration of sediment into spaces around the boulders. No gravel layers were observed within the matrix of the Loliwe palaeotalus deposit, but sedimentary layering, in places draped over larger clasts, does occur, and it is not unreasonable to contend that this evidence would be equally supportive of infiltration which occurred after the accumulation of the talus. The Loliwe palaeotalus has been preserved *in situ*, and it is suggested that deposits similar to this were very common along the fault-line-scarp bounded northwestern margin of the basin. The talus from the quartzite kranes provided the material which was transported downstream to be laid down as gravels which now form the Ulundi Member conglomerates deposited as intermontane and alluvial fan conglomerates along the western boundary of the northern portion of the basin (Fig. 6.1d and e). The palaeotalus deposits, exemplified by the deposit at Loliwe, are thus seen to be proto-Natal Group deposits - the initial deposits preserved within the basin.

6.2.3 DEPOSITION OF DURBAN FORMATION

6.2.3.1 Introduction: There must have been a change in conditions in the basin, from the erosional environment which had prevailed and allowed ~8 km of basement to be removed

(see Chapter 5), to an environment allowing the deposition of molasse sediments derived from the Pan-African mountains in southern Mozambique (see Ryan, 1967). This was effected by the activation of the already-existing Melville Thrust to form the moderately-elevated Dweshula High and the basement ridge near Pietermaritzburg (Fig. 6.1e). Although no rocks resulting from sediments shed off the Pietermaritzburg Ridge have been identified, there are Ulundi Member conglomerates in the southwestern corner of the basin which are thought to have been derived from the Dweshula High. It is also highly probable that some tilting of the basin in a northward direction occurred, in effect reducing the axial gradient, and thus terminating the erosional regime and initiating the depositional phase during which the Natal Group was deposited (Fig. 6.1f).

6.2.3.2 Ulundi Member: Blair and Mc Pherson (1994) list the optimal conditions for the formation of alluvial fans. The present study has provided evidence that all these conditions were present in the northern portion of the basin where the Ulundi Member was deposited. It is therefore not unreasonable to presume that alluvial fans were formed. Firstly there was the juxtaposition of a relatively uplifted mountain block, and a valley - along the western margin of the Natal Trough graben. Secondly, there was the presence of feeder channels which drained the upland catchment area transversely across the scarp into the valley. Thirdly, much coarse sediment produced by mechanical weathering was available for transport into the basin, as seen at Loliwe. The unweathered feldspars in the arenaceous deposits provide substantiating evidence for this. The debris flows and "hyperconcentrated flood flow" (see Smith, 1986, p.2) bear witness to the presence of the fourth element, namely infrequent but intense rainfall which caused flash-flood discharge. Fifthly, the common occurrence of faulting near, and approximately parallel to, the western

margin of the Natal Group basin is concomitant to the postulation of a fault-bounded basin, or graben.

The several types of conglomerate observed can be used to interpret: a) in which of the four parts of the drainage system (Miall, 1981a) they were deposited; and b) which mechanism or combination of mechanisms was instrumental in transporting and depositing the gravels.

The shape of the Ulundi conglomerate clasts suggests that the conglomerates are of fluvial origin (See Chap. 4 - Description of Ulundi Member). The size of the clasts - up to 2 m diameter - (Matthews 1961; Hobday and von Brunn, 1979) and the generally matrix-poor character of the conglomerates, testify to the **high** energy of the transporting streams, consequent upon the high relief of the area, caused by the formation of the foreland graben. In this connection, the conglomerates of the van Horn Sandstone, in the U.S.A., provide evidence of extremely high transporting stream competence related to the confinement of water flow to narrow canyons (Mc Gowen and Groat, 1971). It is postulated that some of the conglomerates of the Ulundi Member - those with sparse matrix and elongate valley morphology - were laid down under much the same conditions. This would have been largely in the headwater zone (see Miall, 1981a) as valley fill fluvial deposits in intermontane valleys (Hobday and von Brunn, 1979; Matthews, pers.comm.⁹), and in the proximal zone (see Miall, 1981a) as alluvial fans. The Ulundi Member deposit along the White Mfolozi River (Marshall, 1991a) with its tabular geometry, sparse matrix and interbedded shales and sandstones, commonly cross-bedded, is part of an alluvial fan,

⁹ Prof. P.E. Matthews, Dept. of Geology, University of Natal, Durban

whereas the deposit in the valley of the Nsuzze River (Marshall, 1991b), with its elongate valley geometry and greater matrix content than at Ulundi, was deposited as valley fill.

It is proposed by the author that some gravels moved as high density dispersions along the bottoms of the river valleys (headwater zone of Miall, 1981a) during floods of high magnitude, as "high density bedload carpets" (Todd, 1989, p. 517), being moved by "hyperconcentrated flood flow" (Smith, 1986, p.2). Some matrix-supported conglomerates, with relatively angular clasts which are commonly aligned horizontally were deposited as debris-flows. The valley-fill deposits, with abundant matrix, such as seen in the valley of the Insuzze River, are interpreted as the m_2 facies of Ghibaudo (1992), and resulted from the frictional freezing of a highly-concentrated clast dispersion which had moved as a high density turbidity current (see Lowe, 1982). Where the gravels were dispersed onto the proximal portion of the depositional basin, and deposited as a fan, the intensity of the processes within the environment was diminished, and the transport of the clasts would have been by traction of normal stream flow (Smith, 1986) along the floor, with individual particles being transported as part of the normal stream bedload. It is in this type of environment that imbrication and stratification within the beds was produced. The high density dispersions which were deposited within the fluvial valleys would have had more finer-grained material which was deposited at the same time as the matrix than the gravels deposited by normal traction flow. In the fan deposits, where the gravel was not transported as a cohesive mass, the finer-grained material was, to a greater degree than the valley deposits, removed and transported further into the basin, to be deposited as arenaceous and argillaceous beds. At this stage, the matrix material was flushed out by the stream, resulting in a clast-supported conglomerate with little or no matrix. Thus, the

conglomerates with abundant matrix are interpreted as more proximal than those with little matrix. Any matrix in the more distal conglomerates was probably the result of infiltration of later arenaceous sediments, and provided no additional strength to the framework clasts (Reddering, pers. comm.¹⁰). Matrix-supported conglomerates, and clast-supported conglomerates with abundant matrix, which occur in the proximal zone (see Miall, 1981a) are seen to be debris-flow deposits. Rodine and Johnson (1976) have described debris-flows which have flowed on gentle slopes.

6.2.3.3 Eshowe Member: As the erosional regime was replaced by conditions conducive to deposition of the molasse sediments derived from the Pan African mountains in southern Mozambique, the arkosic to sub-arkosic sandstones and interbedded shales and siltstones of the Eshowe Member were formed, penecontemporaneously with the conglomerates and interbedded arenites of the Ulundi Member.

Miall (1981b), in describing the Platte River type of depositional environment, and the resultant facies assemblage for low-sinuosity, multiple-channel rivers, stated that the sediments are dominated by linguoid or transverse sandy foreset bars, or by sand waves, giving rise to a dominance of planar cross-bedding. The sparse occurrence of trough cross-bedding is attributed to the rarity of deep channels. In this light, the Eshowe Member south of Eshowe was deposited by exceptionally broad, shallow rivers with no well-defined topographic differentiation between active and inactive areas. The increase in the incidence of trough cross-bedding northwards is to be expected, as deeper channels would be present near the points of discharge from the intermontane drainage channels.

¹⁰ J.S.V. Reddering, Council for Geoscience, Port Elizabeth.

The predominance, in the Eshowe Member, of lithofacies Sh and Sp (Table App-1.3) would suggest that the Eshowe Member was laid down from a river of the Bijou Creek Type (see Miall, 1978). The common occurrence of lithofacies Fl - indicating overbank or waning flood deposits (see Miall, 1978) - and St - indicating dunes and lower flow regime, would suggest that the Bijou Creek Type rivers tended towards rivers of the Platte Type (see Miall, 1978). In other words, the rocks of the Eshowe Member have characteristics of sediments deposited by both the Bijou Creek and Platte River types.

In the proximal zone, the Eshowe Member sediments were deposited on top of the Ulundi Member fan conglomerates. More distally, the arenaceous sediments with interbedded argillaceous sediments were deposited directly onto the basement floor of the basin. This member was deposited by superimposed transverse bars (as shown by stacked planar cross-bedded units) topped by smaller bedforms such as sandwaves and megaripples (as shown by trough cross-bedding). Current velocities ranged from low velocity as reflected in tabular foresets, through high velocity, to upper flow regime preserved as plane beds (see Harms and Fahnestock, 1965). As there was no vegetation present during the Pre-Devonian Natal Group times (see Fuller, 1985), the rivers were not confined by well-defined banks protected by vegetation, and the lateral limits of rivers were determined by a) the topography and b) the amount of water present. As suggested by Hobday and von Brunn (1979), the common occurrence of siltstones and shales overlying coarser sandstones, would suggest overbank deposition on areas of the braided stream which were inactive.

As flow was reduced from the high and moderate velocity described above, and the competence of the river was diminished, the finer grained sand and silt was deposited as

lithofacies Fl. As flow was reduced still further, the width of the rivers would have decreased, and overbank pools (backswamp, Miall 1978, or interchannel areas) would have been left on the braidplain. The fine sediment in suspension would then have been deposited as clay drapes (lithofacies Fsc), to become more cohesive during subsequent exposure to the atmosphere. Some of the rivers would cease flowing completely, and the resulting pools would deposit clay drapes in a manner identical to that described for overbank or waning flood deposits initially, and then for the deposits in the interchannel areas. The thickness of lithofacies Fsc or Fl deposits would give some indication of the depth of the backswamp or central stream pools during reduced flow and quiescent conditions. Where the initial flow of a flood event was strong enough, scouring and removal of the armouring layer of argillaceous material would be removed, and the underlying sand would also suffer erosion, and the resulting channels would be filled by coarse sand, commonly with lag deposits at the base. Argillaceous beds are more common in the southern (medial) portion of the basin than in the northern (proximal) portion, which is to be expected.

During the deposition of the Eshowe Member, there was apparently much more water present in the north than in the south, as shown by the prevalence of soft-sediment deformation in the north, and its complete absence in the south (Matthews, 1961). The evidence of contemporaneous volcanism (Marshall *et al.* 1991; Thomas *et al.* 1992) would suggest that there was some earthquake activity at this time, which could have helped to trigger the unstable sediments into movement resulting in the soft-sediment deformation. The undulatory floor of the basin would have been filled by playa lakes in which relatively thick argillaceous deposits were formed (Roberts, 1981).

6.2.3.4 Kranskloof, Situndu and Dassenhoek Members: As the provenance area to the northeast became lowered by continued erosion, the Eshowe Member became progressively finer upwards, and the sediment supply also diminished. The Kranskloof and Dassenhoek Members resulted from the reworking and winnowing of Eshowe Member sediments during this period of very little or no sediment influx from the mature provenance area which had little or no relief. The immediate provenance of the Kranskloof Member was, therefore, in the northern portion of the Natal Group basin, and the absence of quartz arenites to the north of the Mhlatuze River would be explained by this, rather than resorting to a northern limit of marine transgressions as proposed by Roberts (1981), Visser (1974) and others. Wind-winnowing would have also played an important role in removing the finer particles to produce the quartz arenites of the Kranskloof Member (see Fuller, 1985). The unweathered nature of the feldspars, and the winnowed nature of the quartz arenites in which they occur sparsely, would imply a semi-arid climate at the time of deposition of the Kranskloof Member (see Visser, 1974; Roberts, 1981; Fuller, 1985). It is contended that the Dassenhoek Member was deposited under conditions very similar to those of the Kranskloof Member, and it is thus envisaged as a sedimentary continuation of the Kranskloof Member. The presence of the coarse, arkosic to sub-arkosic sandstones of the Situndu Member, with very sparse argillaceous material, between the Kranskloof and Dassenhoek Members, is interpreted as follows: There was a short-lived rejuvenation of the drainage, consequent upon uplift in the provenance area in Mozambique. This was possibly a precursor to the major uplift which allowed the transport and deposition of the small-pebble conglomerates of the Tulini Member at the base of the Mariannahill Formation, and resulted in the influx of coarse sediments. Some of the finer material would have been deposited as the interbedded, relatively scarce, shale beds, and the rest transported beyond

the known portion of the basin.

At the base of the Kranskloof Member are what Roberts (1981) termed intertidalites. He envisaged these as being transitional between the fluvial Eshowe Member and the shallow marine Kranskloof Member. As discussed later in this chapter, the quartz-arenitic rocks of the Kranskloof Member, are regarded as fluvial deposits, and the term "intertidalite" is therefore inappropriate. The interbedded sub-arkoses, argillites and quartz-arenites, with cross-bedding and reactivation surfaces, indicate a transition from the deposition of the first-cycle, immature, arkosic sediments of the Eshowe Member to the more mature, reworked quartz-arenites of the Kranskloof Member.

At the cessation of the deposition of the Situndu Member, the conditions prevalent in Kranskloof times resumed, and the Dassenhoek Member was deposited. This marked the culmination of the Durban Formation, which commenced with coarse conglomerates of the Ulundi Member, followed by coarse- to finer-grained arkosic sediments of the Eshowe Member, which were winnowed and reworked to provide the material for the quartz-arenites of the Kranskloof and Dassenhoek Members during a period of sparse sediment supply from the reduced Pan-African provenance in Mozambique. There was a temporary interruption of this last environment to produce the coarse, arkosic sediments of the Situndu Member, as described above.

6.2.4 DEPOSITION OF MARIANNHILL FORMATION

6.2.4.1 Introduction: The deposition of the five members of the Durban Formation formed

a cycle which closed with the initiation of a second cycle during which the Mariannahill Formation was deposited.

6.2.4.2 Tulini Member: Dobkins and Folk (1970) stated that a figure greater than 0,65 for the maximum projection sphericity indicates a fluvial depositional environment. Also, they maintained that if the oblate/prolate index falls between -1 and +5, it is 69% certain to be fluvial. Stratten (1974) stated that a coefficient of flatness of more than 45 indicates a fluvial origin. Table 3.6 lists the results of the analyses of the pebble measurements. Plots of maximum projection sphericity vs. coefficient of flatness (Figs. 3.45 to 3.56), as proposed by Stratten (1974) point conclusively to a fluvial environment of deposition.

The Mariannahill Formation was initiated by deposition of the Tulini Member which is seen to have occurred in response to rejuvenated drainage reflecting either uplift in the provenance areas, or accelerated subsidence of the foreland graben of Thomas *et al.* (1993). Either of these processes would have increased the competency of the streams, and resulted in the widespread development of the small-pebble conglomerates. North of the Tugela Thrust Front (Fig. 3.43) the matrix-supported nature of the polymict conglomerates of Facies B, occurring in elongate fan deposits, are seen to have been deposited by debris-flows. South of the Tugela Thrust Front, the monomict (quartz) and clast- to matrix-supported conglomerates of Facies A are interpreted as having been deposited on an alluvial braid-plain in the medial zone (see Miall, 1981a) by rivers of the Scott Type (see Miall, 1978). This braid-plain extended from the Tugela Thrust Front in the north to Verulam in the south. Ferricrete (10 cm thick) in a conglomerate at Clantrock northeast of Wartburg (Marshall, 1991b) would indicate prolonged exposure to the atmosphere during relatively dry conditions. The difference between the composition of the clasts of Facies

A and B points to the two facies being derived from two independent provenances. Facies B, with polymict supracrustal clasts, was probably derived from the craton to the north, whereas Facies A, with monomict (quartz) clasts, was probably derived from quartz veins in the Tugela Thrust Front. The remarkable uniformity of the means of: a) elongation, b) oblate/prolate index, c) ratio of short axis to intermediate axis, d) ratio of intermediate axis to long axis, e) coefficient of flatness, f) maximum projection sphericity, g) bladedness and h) nominal diameter (Fig. 3.57) for 12 localities in the Type Area, indicates to the author that the deposits of Facies A shared a common provenance, transport and depositional history, thus confirming a similar idea suggested by the monomict nature of the conglomerates.

6.2.4.3 Newspaper Member: As the Natal Group basin continued to subside, the braided rivers of both Platte and Bijou Creek Types continued to supply the sub-arkosic to arkosic sands and muds which are now represented by sandstones and interbedded silts and shales of the Newspaper Member. As the lithologies, palaeocurrent directions and sedimentary structures of the Eshowe and Newspaper Members are essentially the same, the author suggests that the provenance, and conditions of transport and deposition were also essentially the same as for the both members.

There are, however, several differences which need to be addressed.

The first is the presence, in certain zones within the Newspaper Member, of calcitic concretions of varying sizes, but with a maximum of approximately 3 cm. These are diagnostic of the Newspaper Member, and were not encountered in any other unit of the

Natal Group (see also Roberts, 1981). The author also identified calcite cement in some of the samples taken from the Newspaper Member rocks. It is suggested that the calcite was deposited as a diagenetic cement, possibly from fluvial water that was left in the pore spaces, and later concentrated as small concretions during diagenesis.

The second difference is the very common occurrence of soft sediment deformation. Matthews (1961) reported on this phenomenon, pointing out that south of Durban it is restricted to the Newspaper Member, whereas northwards from Durban the deformation occurs progressively lower down in the succession, until just south of Ulundi it was observed to occur from the base of the Eshowe Member to the top of the Newspaper Member. He proposed that the slumping was caused by sliding on the depositional slope, resulting from either overloading or removal of the toe of the deposit by scouring, thus producing instability. He also suggested that one of the possible causes of the slumping was an increase of the slope on which the sediments were deposited, as a result of regional tilting, which apparently affected only the eastern part of the known depositional basin. He attributed the dearth of slumping evidence in the western portion of the basin to this.

Matthews reasoned that this hypothesis leads to some speculation regarding the deposition of the Natal Group rocks. He suggested that if the lowermost slumped beds were formed during the earliest phase of tilting, then the apparent distribution of these slumped beds indicates that this movement occurred when a greater thickness of sediments had been deposited in the southern part of the area than in the north. He wrote at a time when there was no stratigraphic subdivision of the Natal Group at all. The present stratigraphic subdivision of the Natal Group makes it inconceivable for slumping in the Newspaper

Member south of Durban to have been contemporaneous with slumping at the base of the Eshowe Member near Ulundi, taking into account the occurrence of widespread marker layers (Kranskloof and Tulini Members) which occur between the Eshowe and Newspaper Members.

If basin-floor tilting was a cause, it would have had to have occurred progressively, commencing in the northern portion of the basin, and extending to the south as the basin filled. This mechanism is necessary to explain the occurrence of soft-sediment deformation near the base of the Eshowe Member in the Melmoth/Ulundi area, and its restriction to the Newspaper Member south of Durban. Lourens (1979) added that gravity was the underlying mechanism which operated in all situations. Roberts (1981) cited liquefaction of saturated sediments - possibly triggered by seismic activity - as a possible cause of slumping. Another mechanism suggested by Roberts is current turbulence which could have caused both slumping and recumbent foresets. Water-release structures were probably caused by fluidization - a common process in braided-stream and alluvial fan environments (Roberts, 1981).

6.2.4.4 Westville Member: Deposition resulted from rejuvenation of the drainage caused, possibly, by uplift in the provenance area, or, alternatively, by renewed subsidence of the foreland graben proposed by Thomas *et al.* (1993) or the failed rift of Hobday and von Brunn (1979). The conglomeratic sandstones of the Westville Member provide evidence of further rejuvenation of the drainage. These deposits are sporadically developed over most of the basin as far south as Mid Illovo, southwest of Durban. The generally well-rounded, polymict clasts are usually matrix supported, and are thought to have been derived

from a relatively distant source, and provide evidence of a fluvial origin (Roberts, 1981). The clast shape parameters (Fig. 3.63; Table 3.6) would support the fluvial hypothesis.

This unit is perceived to represent the distal phase of fan conglomerates, and the braided rivers which flowed southwards beyond the fans. Roberts (1981) analysed the depositional environment of the Westville Member as follows: In a braided river environment, channel scours with pebble lags produced conglomerate lenses within the planar cross-bedded sandstone deposited by transverse bars. Turbulence caused by increased flow, as indicated by the greater number of pebbles - the pebbles being larger than the random phenoclasts in the underlying Newspaper Member, and thus showing greater competence - mobilised the water-saturated sediments, causing soft-sediment deformation.

6.3 DISCUSSION

6.3.1 MAXIMUM THICKNESS OF THE NATAL GROUP.

It remains uncertain just how thick the Natal Group was at its maximum development. The fracturing of the Ulundi Member clasts indicates a thickness of 1300 m to 2600 m, prior to consolidation (Chap. 4). The removal of the upper portions of the Natal Group is suggested to have been caused partially by subaerial erosion and partially by the Dwyka glacial activity. The erosive activity of the Permo-Carboniferous Dwyka glaciation is clearly shown by a) glaciated pavements on the upper surface of the Natal Group (Fig. 5.2; von Brunn and Marshall, 1989), b) the presence of clasts of indurated Natal Group within the Dwyka diamictite (Fig. 6.2), and c) by the difficulty, locally, in identifying the contact



Fig. 6.2 Clasts consisting of Natal Group in Dwyka Group diamictite, resting on Natal Group, south of Cato Ridge. (Photo by V. von Brunn)

between the basal Dwyka Group rocks and the Natal Group rocks. Du Toit (1946) reported on a similar phenomenon. This difficulty is the result of the erosion and entrainment of large quantities of Natal Group arenaceous material by the eroding Dwyka ice sheet from which the sandy debris was subsequently deposited. In the south, however, for example at Wood Grange (Fig. App-2.15), the Devonian Msikaba Formation lies between the underlying Newspaper Member and the overlying Dwyka Group, with the implication that, at this locality, the removal of the upper portion of the Natal Group was effected prior to the Dwyka glaciation.

From the above, it is contended that the Westville Member marks the initiation of a third cycle of sedimentation, in which case it would be the basal conglomerate. There is, however, at this stage, insufficient evidence for the establishment of a third formation in the Natal Group.

6.3.2 SOUTHERN LIMIT OF THE NATAL GROUP SEDIMENTATION.

Quite conceivably, some of the Natal Group sediments spilled over the Dweshula High, and were deposited in the basin of the Msikaba Formation to the south. No lithological evidence of this is found, but the persistence of the N-S palaeocurrent pattern right down to the southern margin of the Natal Group basin would suggest that the southern limit of this unit was further south than is now observed.

6.3.3 NORTHWARD EXTENSION OF MSIKABA FORMATION .

After cessation of deposition of the Natal Group, there was a long period (~140 Ma) of erosion. During this period (from the Ordovician to the Devonian) an erosional regime is presumed to have prevailed, as there is no evidence of any sedimentation, and the upper portions of the Natal Group, and the basement rocks to the south, were eroded. In the Devonian, the quartz-arenites of the Msikaba Formation were deposited in the basin situated where southern KwaZulu-Natal and Pondoland are now located. What is now known as the Msikaba Formation was assumed by Rhodes and Leith (1967), Kingsley (1975), Visser (1974), Hobday and von Brunn (1979), and other workers, to have been deposited in shallow marine conditions. A cursory survey of the palaeocurrent directions recorded by other workers - confirmed by the few measurements taken by the author - reveals what appears to be a consistent northeast to southwest direction, which, under certain circumstances can occur in marine deposition (Reddering, pers. comm.¹¹). The Msikaba Formation beds overlapped onto the Natal Group in the vicinity of Port Shepstone (Fig. 6.1g; App-2.15), but may have extended much further north (Roberts, 1981). There is, however, no evidence of any such northward extension.

6.3.4 PALAEOCLIMATE

The original detrital grain boundaries in virtually all the arenaceous rocks of the Natal Group are marked, in the majority of cases, by haematite dust rims (Fig. 3.33 a & b). This thin haematite coating on the majority of the quartz grains was probably deposited on the

¹¹ J.S.V. Reddering, Council For Geoscience, Port Elizabeth.

quartz grains shortly after deposition. Eriksson (1983) has stated that ferruginous cuticles are unlikely to survive the depositional process of the high-energy environment. However, the iron oxide coating must have been deposited on the quartz grains prior to the formation of the quartz overgrowths. The iron oxide was probably derived by the action of intrastratal fluids on the iron-bearing silicate detrital grains (see Walker, 1967) and on iron-bearing clays (see Folk, 1976). This iron oxide coating was presumably deposited as amorphous hydrous iron oxide (limonite), and subsequently altered diagenetically to haematite (see Eriksson, 1983). This last process probably occurred during the silicification of the sandstones. In some instances the iron oxide occurs as intergranular blebs, and it appears as if the iron oxide has been concentrated during the diagenesis. The unweathered nature of the feldspar grains and the iron-staining of the sand grains making up the rocks are taken as evidence that the climate was semi-arid, with intermittent flow of the drainage allowing exposure of the unconsolidated sediments, during which the sand grains would have become iron-stained.

Hobday and von Brunn (1979) stated that the monomict nature of the conglomerates, with almost exclusively quartzite clasts, indicates a humid climate of deposition, as non-resistant clasts would have been broken down during transport and storage. The author, however, feels that the environment was semi-arid with ephemeral streams being fed by flash floods of high energy, interspersed by periods of exposure of the sediments to the atmosphere, during which the sand grains would have been stained by the iron oxide present. Walker (1967) indicated that debris flows suggest ephemeral drainage, as debris-flows do not form on wet fans formed by perennial drainage, but are common on the dry fans formed by ephemeral drainage. Roberts (1981) was of the opinion that the climate, at least in early

Natal Group times, was hot and arid. Had a humid climate, concomitant with perennial rivers and abundant water supply, been prevalent, the very fine-grained clay and iron oxide content would have been winnowed out, to be deposited further downstream in the basin, as shale layers. The author's contention that the streams were ephemeral is supported by the presence, in the Eshowe Member sandstones, of ferruginous clay drapes - on reactivation surfaces - that are presumed to have been deposited during conditions of reduced flow. Only exposure to the atmosphere would have allowed the clay drapes to become somewhat dehydrated and more cohesive, and hence preserved during the subsequent highly-erosive flow event, and therefore able to protect the underlying, otherwise vulnerable, sand bed from erosion. The abundance of water necessary for the saturation of the sediments leading to soft-sediment deformation, would have been provided by the sporadic and yet intense rainfall of the semi-arid climate.

The northern assemblage is a red-bed sequence insofar as the maroon colour of the rocks is an intrinsic property of the rocks, and not a present-day surface weathering effect (see Walker, 1967). The association of arenites and argillites is also typical of such deposits. This fits Pettijohn's (1975) concept of red-beds as being oxidised molasse deposits. Borehole core from Kloof (400 m deep and drilled for the Geological Survey) and Hlabisa (476 m deep and logged by the author) exhibit the typical reddish to maroon-red colours seen at surface. The patchy occurrence of red colour in the southern assemblage (Fig. 6.3) is, on the other hand, purely a surface weathering phenomenon, and is the result of the break-down of ferruginous minerals, the products of which have stained the surrounding rock. This phenomenon was also recorded by Schwarz (1917).



Fig. 6.3 Patchy iron-staining of Msikaba Formation quartzite, derived from surface weathering of ferruginous minerals in the quartzite, Woodgrange.

The lack of a Kibaran date component in the sample dated (Thomas *et al.* 1992) indicates that the climate was semi-arid, and that there was virtually no admixture of sediments from the nearby Kibaran terrain, after the initial basal rudaceous sediments were deposited. The immaturity of the sediments, the unweathered nature of the feldspars, and the iron-staining of the sand grains prior to silicification, testify to fairly arid conditions in the provenance area, where flash-floods would have periodically removed the accumulated products of mechanical weathering, as well as in the basin of deposition. Prolonged flow conditions sometimes produced thick (in excess of 1,5 m) sets of cross-bedding (Fig. 3.24).

6.3.5 CLAST SHAPE PARAMETERS

In Figs. 3.4 (Ulundi Member); 3.45-3.56 (Tulini Member) and 3.67 (Westville Member), the coefficient of flatness of clasts, plotted against maximum projection sphericity, shows a marked concentration in the field representing a fluvial depositional environment (see Stratten, 1974). However, Reddering and Illenberger (1988) pointed out that the method of Stratten (1974) is flawed in that it is based on observations by Dobkins and Folk (1970) who ignored the more equant clasts in the deposits on Tahiti-Nui (Reddering, pers. comm.¹²). Thamm (1988b), however, contended that this type of shape-sorting has a negligible effect on the hypothesis that a fluvial environment can be detected by plotting sphericity against flatness. Reddering also pointed out (pers. comm.) that the linear pattern revealed in the figures indicates that the two parameters being plotted are essentially the same. The author, however, would suggest that, if there is any credibility in the Stratten assumption, then the presence of the plots within a field is significant, even if there is a

¹² J.S.V. Reddering, Council for Geoscience, Port Elizabeth.

certain linearity.

The sphericities of the Ulundi Member clasts at Nsuze are lower than in the Tulini Member, and it is considered that the difference is due, not to the depositional environments, but rather to the length of time the clasts were being transported. The Ulundi Member clasts are also considerably larger than those of the Tulini Member, which is suggestive of shorter transport distances. However, the size of the material available at source would have had a strong influence on the size of the clasts ultimately deposited.

6.3.6 TERRESTRIAL / MARINE ORIGIN OF KRANSKLOOF AND DASSENHOEK MEMBERS

Kingsley (1975) was the first, apart from Schwarz (1917) to recognise that the quartz arenites of what is now known as the Kranskloof Member of the Durban Formation, were laid down in fluvial rather than shallow marine conditions. All other workers (du Toit 1931, 1954; Mathew 1971; Hobday *et al.* 1971; Visser 1974; Hobday and von Brunn 1979; Tankard *et al.* 1982; and Roberts 1981, 1990) suggested that the Kranskloof Member quartz arenites were laid down in a marine environment during marine a transgression (or transgressions) of the sea which deposited the Pondoland deposits of what is now known as the Msikaba Formation.

If the rocks of the Kranskloof and Dassenhoek Members were laid down under tidal conditions, as is implied by the authors who advocate a (shallow) marine origin for these rocks, then they should exhibit certain characteristics typical of tidalites, and which would reflect the tidal conditions of deposition.

Klein (1977) compiled a list of features diagnostic of rocks deposited in tidal conditions. Of those felt to be critical to the distinction between tidalites and fluvial deposits, the following were not observed during the present investigation.

A. The evidence of the bipolar reversal of flow direction:

- a) bimodal-bipolar distribution of the maximum dip direction of the cross-bedding / herringbone cross-bedding;
- b) complex internal organization of dunes and sand waves;
- c) supermature rounding of the quartz grains;

B. The evidence of late-stage emergence ebb outflow and emergence with rapid changes in palaeoflow directions at very shallow depth:

- d) multimodal distribution of maximum dip direction of the cross-beds;
- e) small current ripples superimposed at right angles to larger current ripples;
- f) interference ripples;
- g) double-crested or flat-topped ripples; and
- h) symmetrical ripples.

It is therefore suggested that it is highly unlikely that the Kranskloof and Dassenhoek Members are the result of deposition under tidal conditions. They were deposited fluvially.

The thickness of the Kranskloof Member varies quite considerably, but thins rapidly northwards from Stanger and southwards from Hibberdene (Marshall 1987, 1988, 1991a, 1991b, 1991c). This thinning to the south in the southern portion of KwaZulu-Natal is the

reverse of what would be expected had the northern assemblage quartz arenites been deposited during a marine incursion from the south.

Furthermore, Rhodes and Leith (1967), Hobday and Mathew (1974), Visser (1974), Hobday and von Brunn (1979) and Roberts (1990) asserted that the orthoquartzite (now identified as the Kranskloof and Dassenhoek Members) represent a northward extension of the southern assemblage into the northern part of the depositional basin, as the result of a marine transgression. It must be noted that Kingsley (1975) did not subscribe to this theory, and offered an alternative explanation whereby wind-blown sand accumulated in a shallow lake and was reworked subaqueously. The coarser-grained intercalations were assumed to represent river channel deposits.

Significantly, Kingsley (1975) recognised that, in addition to the marked changes in the lithology between Hibberdene and Southport, south of Margate, both sequences thinned against a basement ridge which trends east-west. Thomas *et al.* (1990) also noted a basement high - the Dweshula High (Fig. 1.1; App-2.15) - over which there is no representation of either the northern or southern assemblages, and where the Dwyka Group sediments rest directly on the Kibaran basement rocks. This basement ridge is likely to have formed the southern margin of the red bed deposits of the northern assemblage, and the northern margin of the quartz arenite assemblage to the south. The two assemblages are thus probably separate entities.

Tankard *et al.* (1982) in discussing the accumulation of great thicknesses of quartz arenites in the shallow marine environment of Pondoland, suggested an accelerated subsidence of the Natal Trough as the cause of two or three episodes of marine transgression during

which the multi-cycle deposits of the quartz arenites of the Natal Group were deposited. Chandler (1988) stated that fluvial quartz arenites can result from the fluvial redistribution of wind-winnowed, chemically-weathered, quartz-rich rocks, with the weathering occurring during a relatively humid climatic cycle, and the wind-winnowing during a subsequent relatively arid climatic cycle. The redistribution of the products of the chemical weathering and wind-winnowing would have occurred during intermittently-activated drainage (flash-floods). Chandler (1988) also suggested that the quartz grains of the quartz arenite could be derived from the diagenetic destruction of labile framework grains of immature sandstone. The author suggests that this is the mechanism whereby the Kranskloof (and Dassenhoek) Members were formed.

Kingsley (1975) listed several reasons why the quartz arenites of the Kranskloof Member were not of marine origin, and proposed an alternative depositional mechanism whereby wind-blown sand accumulated in shallow lakes and were reworked subaqueously. Pettijohn *et al.* (1987); Selley (1982) and Suttner *et al.* (1981) have stated that quartz arenites are polycyclic deposits, basing this statement on the mineralogical and textural maturity. However, Dutta (1987) stated that first cycle, fluvial quartz arenites are common in the geological record. Lewis (1984) suggested that quartz arenites were derived from older quartz-bearing sediments. Chandler (1988) stated that Early Palaeozoic fluvial quartz arenites are abundant. He also suggested that there appears to be a strong relationship between intense chemical weathering of rocks containing granular quartz and kaolinite, and the formation of quartz-rich alluvium. Evidence provided, and which is at least partially applicable to the Kranskloof Member, includes poor sorting, kaolinitic matrix, angular quartz grains, and overbank argillites. Chandler (1988) then stated that the Pass Lake

Formation contains 20-80 m of plane-bedded (sheet flood) and cross-bedded (fluvial) quartz arenite. He also stated that some quartz arenites may be deposited under arid climatic conditions. Pettijohn *et al.* (1987) and Mc Bride (1989) stated that quartz arenites formed in stable tectonic environments, but Chandler (1988) cited evidence that they can also form in less stable tectonic environments. Rust and Jones (1987) referred to basin-wide unidirectional palaeocurrent distribution and the abundance of clay intraclasts up to large boulder size, as two of three major objections to the Hawkesbury Sandstone being of marine origin. These objections would apply equally well to the Kranskloof and Dassenhoek Members of the Natal Group. The common occurrence of horizontal stratification (upper plane bed lamination, of Cheel, 1990), taken together with the unidirectional palaeocurrent direction, is a strong indication of the fluvial origin of the Kranskloof Member.

In this regard, the author encountered several occurrences of locally-developed quartz arenites within the sub-arkosic to arkosic sandstones of the Eshowe Member. If all of these are of necessity to be interpreted as the result of marine incursions, there would have been many marine transgressions in the Natal Group. **The** author suggests that they resulted from the reworking, and winnowing of Eshowe Member sediments during local sediment-starvation.

Aspler *et al.* (1994) have shown that large expanses of quartz arenite in the Proterozoic Hurwitz Group of Canada's Northwest Territories were laid down in a shallow, fresh-water lake. This is, in essence, what Kingsley proposed for the deposition of the Kranskloof and Dassenhoek Members. This could also be used to explain the local development of quartz

arenites within the Eshowe Member. It is an alternative to the semi-arid, sediment-starved environment suggested by the author, but it is felt that the massive or horizontally-laminated character of much of the Kranskloof and Dassenhoek quartz arenites would indicate high energy conditions incompatible with lacustrine deposition.

6.3.7 INTERDIGITATION / TRANSITION

Du Toit (1946), Hobday and Mathew (1974), Visser (1974), Kingsley (1975), Hobday and von Brunn (1979) and Roberts (1990), regarded the southern rocks as marine and the northern rocks - apart from the quartz-arenites - as fluvial, and considered the boundary between the southern quartz arenites and the northern red beds to be transitional or interdigitary. Kingsley (1975) suggested that the rocks of his Hibberdene Facies were laid down in a braided river environment whereas rocks of the Margate Facies to the south, which he regarded as contemporaneous, were deposited in a shallow marine setting. He further proposed that the original strand line between the two environments was situated near Margate, but later migrated northwards to where Hibberdene is now situated. It is across this suggested strand line (the interface between marine and fluvial depositional environments) that the interdigitation between the northern and southern assemblages, described by Kingsley (1975), occurred. Marshall *et al.* (1991) and Thomas *et al.* (1992) have shown that there is no evidence for the interdigitation invoked by Kingsley (1975) or the transition of du Toit (1946), and the two occur in juxtaposition at only two localities (Marshall, 1991c). The first of these is on the northern side of the Dweshula High, on the beach just south of Wood Grange where about 20 m of pebbly, grey quartz arenite (called Hibberdene Sandstone Formation by Kingsley, 1975) occurs overlying the red beds of the

northern assemblage, with an apparently conformable contact. This unit is in turn overlain by rocks of the Dwyka Group. The actual contacts are obscured by beach sand. Kingsley, while recognising the lithological similarity between the quartz arenites of his Margate Facies, and the Hibberdene Sandstone Formation, failed to place the latter where it belongs - in the southern assemblage (Kingsley's Margate Facies).

The other locality where the northern and southern assemblages are in vertical juxtaposition is at Rock of Gibraltar, on the southern side of the Dweshula High, some 20 km northwest of Port Shepstone. Here a thickness of some 50 m of northern assemblage red beds underlies the body of southern assemblage quartz arenites, apparently conformably. The red-beds at this occurrence thin rapidly southwards until they are completely absent on the road between Port Shepstone and Izingolweni, and the pale grey quartz arenites of the southern assemblage rest directly on the Kibaran Basement rocks (Fig. 6.4).

Thomas *et al.* (1992), using $^{40}\text{Ar}/^{39}\text{Ar}$ step-heating, have shown that the northern assemblage rocks have an age of ~490 Ma. This Ordovician age is considerably older than the Devonian age ascribed to the southern assemblage by Lock (1973) on palaeontological evidence. The disparity in ages between the two assemblages makes the suggested transition or interdigitation between the northern and southern assemblages impossible.

The suggestion of interdigitation between the northern and southern assemblages, or transition from one to the other, are only possible because of the failure of workers to recognise a) the break in sedimentation over what is now known as the Dweshula High (Thomas 1988), b) the actual observed southward thinning of the quartz arenites in the

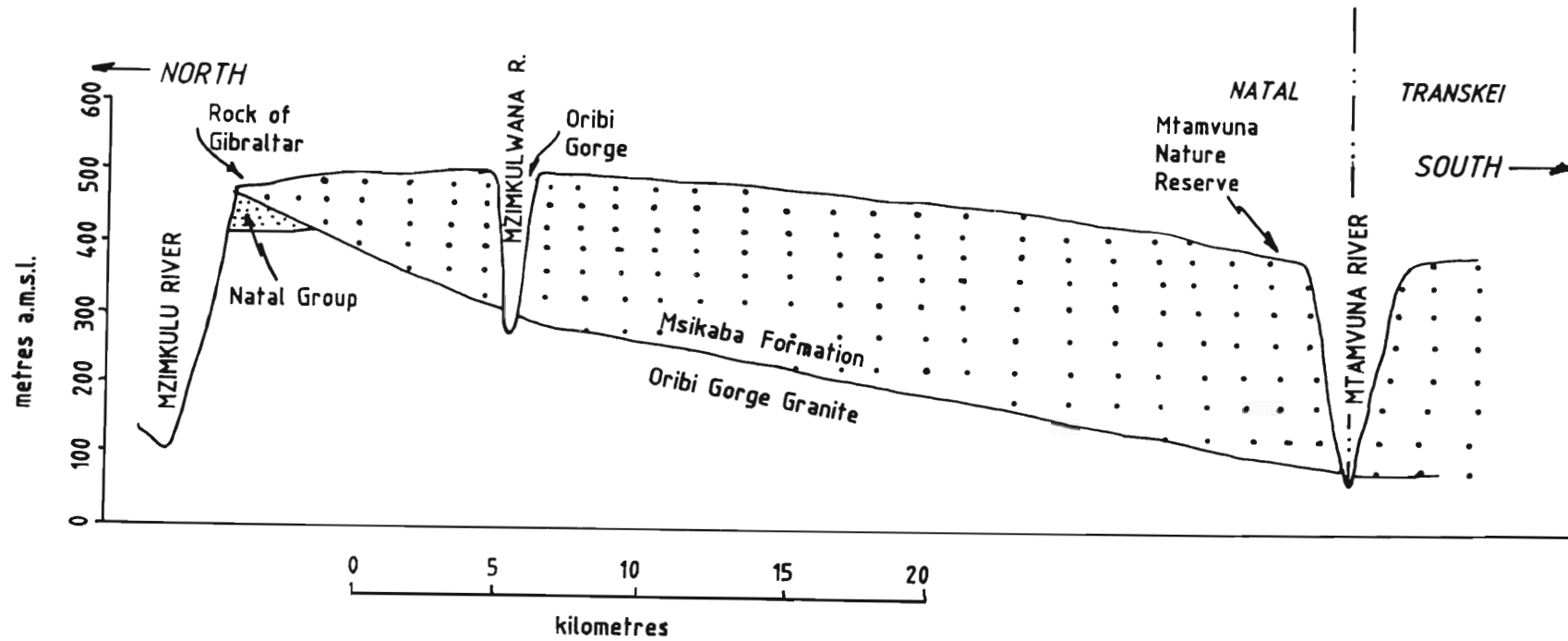


Fig. 6.4 Longitudinal section through Rock of Gibraltar, Oribi Gorge and Mtamvuna Nature Reserve, showing Msikaba Formation overlapping Natal Group.

southern portion of the basin, and the ~140 million years age difference. It is perhaps important to note here that some writers stress the similarity between the rocks of KwaZulu-Natal and those of the Cape Province, while others stress the marked difference. This disparity is considered to be partially the result of the failure to recognise the gap in sedimentation north of Port Shepstone, and the lithological contrast across this gap.

To account for the lithological disparity between what were assumed to be correlates, various authors have proposed tectonically-controlled conditions of deposition (See Chapter 5., Basin Tectonics). They claimed that there was a marine environment of deposition for the southern assemblage in a downwarped trough which deepened to the south and southwest, and a fluvial depositional environment for the northern assemblage.

The two quartz arenites of the northern assemblage (Kranskloof and Dassenhoek Members) are lithologically very different from those of the southern assemblage (Msikaba Formation), and the following table, Table 6.1 illustrates the lithological differences.

Kingsley (1975) questioned the probability of the occurrence of such a large transgression - of the magnitude of 220 to 250 km - in the light of contemporaneous thought. He also drew attention to the presence, in the northern assemblage, of red mudstone with associated large-scale ripple-marks - an indication of a terrestrial environment rather than marine. Therefore, the quartz arenites of the northern assemblage cannot be considered as a northward extension of any part of the southern assemblage of Pondoland marine deposits.

Table 6.1 Lithological differences between the quartz arenites north and south of the Dweshula High.

NORTHERN QTZ. ARENITE	SOUTHERN QTZ. ARENITE
The rocks are fine-grained to medium-grained	The rocks are mainly coarse-grained
The rocks are moderately even-grained	The rocks are pebbly
The colour is maroon	The colour is pale grey
Interbedded maroon-coloured, micaceous shales are common	Argillites are extremely rare, and not maroon in colour
Cross-bedding is rare	Cross-bedding is very common

6.3.8 HAEMATITE

Roberts (1981) noted that the intensity of occurrence of haematite dust rims is directly related to the occurrence of heavy minerals in adjacent laminae, particularly in the Kranskloof Member, and suggested that the haematite coating of the quartz grains resulted from a post-depositional release of iron from the iron-bearing heavy minerals, and a redeposition on the quartz grains. He referred to Walker (1967) who proposed an authigenic origin for the haematite which stains the late Palaeozoic red-beds of Colorado. It is uncertain what caused the bleach spots, but Rowsell (1969) reported on the presence of possible carbon in the centres these leach spots near Verulam, implying that the bleach spots were the result of reduction of the haematite by the carbon.

The Liesegang banding, which occurs commonly in the Natal Group, is secondary colour banding which almost invariably transects the sedimentary structures in the rock. It is extremely common in the silicified sandstones of the entire Natal Group, and can be mistaken for contorted laminae as produced by soft-sediment deformation, or the foresets in cross-bedded units. It is the result of rhythmic precipitation of iron oxide within a fluid-

saturated rock (Lourens, 1979). The author suggests that Liesegang banding is possibly the result of progressive solution of uniformly distributed iron, and the rhythmic precipitation as haematite. As such, the pH and oxidation potential of the saturating fluid would play important roles. Lourens (1967) and Roberts (1981) both proposed that the haematite which gives the Natal Group rocks their characteristic colour, was positioned subsequent to deposition, and prior to final lithification. The fact that Liesegang banding and leach spots occur at depths of 400 m from surface, in boreholes drilled at Kloof and Hlabisa, provides strong evidence that these are not present-day, surface effects.

6.3.9 PROVENANCE

Sutherland (1868) envisaged the rocks of what is now known as the Natal Group as having been laid down in shallow water, and derived from the granitic basement upon which it rests. The latter portion of this conclusion is probably true for the basal beds of the Eshowe Member where the rocks are particularly coarse and the clasts angular and consisting largely of unweathered feldspar such as encountered at Rock of Gibraltar and Ntabakucasha and on the beach at Wood Grange (Marshall, 1991c). Du Toit (1931) described deeply-weathered, tilted, banded gneiss beneath the unconformity in the Melmoth area, and suggested that the Natal Group sediments were derived from deeply-weathered rocks very similar to those underlying the Natal Group, without actually proposing that the provenance lay within the depositional basin.

Hardie (1958) further warned against the assumption that the presence of feldspar in a sediment indicates local derivation, and cited feldspar which was not eliminated from the

sediments of the Mississippi River after being transported for a distance of 1760 km. He stated that a high percentage of the quartz grains studied under the microscope exhibited undulose extinction, which indicated that the rocks were deposited as second cycle sediments derived chiefly from pre-existing ortho-quartzite series. It should be noted that Hardie wrote at a time when the Natal Group was undivided stratigraphically, and he was therefore forced to generalise, thus recording orthoquartzites as having high feldspar content. The author finds difficulty in reconciling an orthoquartzite source for sedimentary rocks which have such a common occurrence of feldspar. It is also difficult to understand why the presence of rounded chert grains (Hardie, 1958) should indicate second-cycle sediments, unless he is implying that the first cycle was the chemical sedimentary process by which the chert was formed.

Roberts (1990) appealed to an upward-fining trend and higher palaeocurrent variance at the top of the Eshowe Formation (now Member), to suggest that source denudation and a decline in the palaeoslope had resulted in a lower rate of sediment supply. He also stated that the quartz arenites are first-cycle sediments, which appears to be in contradiction to Hardie (1958). Kent (1938), basing his ideas on measured palaeocurrent directions in the Verulam area, proposed that the provenance of the Natal Group rocks was to the northeast.

The presence of clasts of quartzite, chert and jasper within the largely quartzo-feldspathic lithology of the arenaceous rocks of the Natal Group (Marshall, 1987, 1988, 1991a, 1991b, 1991c) suggests that supracrustal rocks were present within the largely granitic terrain of the provenance.

The section on Basin Tectonics (Chapter 5) provides more information on the probable location of the provenance to the northeast, where the Pan African event had resulted in mountain building. It should be noted that Tankard *et al.* (1982) advocated basement reworking of the Mozambique Province during the Late Proterozoic, but pointed out that no syntectonic deposits have been recognised.

7. CONCLUSIONS

7.1 STRATIGRAPHY

A sound, workable stratigraphic subdivision of the Natal Group, applicable to the entire known portion of the depositional basin, from Hlabisa in the north, to Hibberdene in the south, has been developed and tested in the field. The various units constituting the Natal Group have been defined and described. The Natal Group has been subdivided into the lower Durban and upper Mariannhill Formations, in turn subdivided into the Ulundi (conglomerate), Eshowe (arkosic sandstone and shale), Kranskloof (quartz arenite), Situndu (arkosic sandstone) and Dassenhoek (quartz arenite) Members, and the Tulini (pebble conglomerate), Newspaper (arkosic sandstone and shale) and Westville (matrix-supported conglomerate) Members, respectively.

7.2 FACIES AND TRENDS

The Ulundi Member was found to occur only in the far north and far south of the basin, whereas the Eshowe Member was found to extend to the basin limits, and to have its maximum thickness developed as a trough parallel, and central to, the axis of the basin. The Kranskloof Member occurs as far north as the Mhlatuze River, but only sporadically north of the Tugela River. The Dassenhoek Member occurs from Verulam in the north to the southern limit of the basin. The Tulini Member conglomerates are widespread north of Verulam, and fall into two facies: Facies A which is monomict and clast- to matrix-supported with a high CPD, and Facies B which is polymict and matrix-supported with a

low CPD. The dividing line between the occurrence of these two facies coincides approximately with the Tugela Fault, or the southern margin of the craton.

7.3 PROVENANCE AND ENVIRONMENT

The climate is considered to have been semi-arid, with ephemeral streams of high energy fed by intermittent, yet intense, rainfall. The Ulundi Member conglomerates were deposited by fluvial and debris-flow activity as valley fill and alluvial fan deposits along the fault-line scarp of the northwestern margin of the Natal Trough, and along the northern flanks of the Dweshula High in the south. The Eshowe, Situndu and Newspaper Members were deposited by braided rivers of the Platte River and Bijou Creek types, as subsidence of the Natal Trough basin continued. The quartz-arenites of the Kranskloof and Dassenhoek Members mark the end of the depositional cycle initiated by the Ulundi Member, and were deposited as reworked and winnowed sands from the Eshowe Member, as sediment starvation resulted from the diminishing relief in the provenance area, reasoned to be the Pan African orogenic belt in southern Mozambique. The Tulini Member conglomerates mark the initiation of a second cycle of sedimentation, reflecting rejuvenation of the drainage caused by uplift in the provenance area. As the basin continued to subside, the Newspaper Member was deposited under conditions very similar to, but more prolonged than, those of the Eshowe Member. With some 500 m of sediment present, a third cycle of sedimentation appears to have been initiated, and the Westville Member conglomerates were deposited. Because of the possibility that the Natal Group attained a maximum thickness of 2600 m, as determined from the strength of fractured clasts in the Ulundi Member, it is suggested that much of the Natal Group was removed

by erosion, both sub-aerial and glacial.

7.4 KWAZULU-NATAL / PONDOLAND CORRELATION

The validity of the hitherto generally-accepted lithostratigraphic correlation of the Natal Group rocks north of Port Shepstone with those to the south, has been disproved. The rocks in Pondoland are of Devonian age, as shown by palaeontological evidence, whereas the rocks to the north of Port Shepstone have an age of 490 Ma (Ordovician). This latter age was determined by means of $^{40}\text{Ar}/^{39}\text{Ar}$ age dating. The use of the term "Natal Group" is henceforth to be restricted to the post-Kibaran, pre-Dwyka sedimentary rocks north of Port Shepstone, and the previously correlated rocks in southern KwaZulu-Natal and Pondoland are to be called the "Msikaba Formation".

The aims and goals of the project have thus been achieved.

REFERENCES

- ANDERSON, W.A. 1901. *First report of the Geological Survey of Natal and Zululand*. Davis and Sons, Pietermaritzburg, 138 p.
- ANDERSON, W.A. 1904. *Second report of the Geological Survey of Natal and Zululand. West*. Newman and Co., London, 169 p.
- ASPLER, L.B., CHIARENZELLI, J.R. AND BURSEY, T.L. 1994. Ripple marks in quartz arenites of the Hurwitz Group, Northwest Territories, Canada: evidence for sedimentation in a vast, early Proterozoic, shallow, fresh-water lake. *Journal of Sedimentary Research A64*: 282-298.
- BARRETT, P.J. 1980. The shape of rock particles, a critical review. *Sedimentology* 27: 291-303.
- BELL, F.G. 1983. *Fundamentals of Engineering Geology*. Butterworths, London, 648 p.
- BENNETT, P. AND SIEGEL, D.I. 1987. Increased solubility of quartz in water due to complexing by organic compounds. *Nature* 326: 684-686.
- BLAIR, T.C. AND Mc PHERSON, J.G. 1994. Alluvial fans and their natural distinction from rivers. *Journal of Sedimentary Research A64*: 450-489.
- BOGGS, S. Jnr. 1987. *Principles of sedimentology and stratigraphy*. Merrill Publishing Co., Columbus, 784 p.
- BOTT, M.H.P. 1976. Formation of sedimentary basins of graben type by extension of the continental crust. *Tectonophysics* 36: 77-86.
- BRAUTESETH, S.V. 1970. The nature of the Table Mountain Series in southern Natal, with special reference to the distribution of the Orthoquartzite Marker. *Petros* 2: 4-9.
- CAIRNCROSS, B. 1989. Paleodepositional environments and tectono-sedimentary controls of the postglacial Permian coals, Karoo Basin, South Africa. *International Journal of Coal Geology* 12: 365-380.
- CHANDLER, F.W. 1988. Quartz arenites: review and interpretation. *Sedimentary Geology* 55: 105-126.
- CHEEL, R.J. 1990. Horizontal lamination and the sequence of bed phases and stratification under upper flow regime conditions. *Sedimentology* 37: 517-529.
- COLE, D.I. AND BASSON, E. 1986. Hewlett-Packard HP-67 Program to correct palaeocurrent data for structural dip and compute vector statistics. *Annals of the Geological Survey of South Africa* 20: 12 p.
- COLLINSON, J.D. AND THOMPSON, D.B. 1982. *Sedimentary Structures*. George Allen and Unwin, Sydney, 194 p.
- DOBKINS, J.E. JNR. AND FOLK, R.E. 1970. Shape development on Tahiti-Nui. *Journal of Sedimentary Petrology* 40: 1167-1203.
- DODSON, R.G. 1951. The geology of the Shongweni District, Natal. *Unpublished M.Sc thesis*, Univ. Natal, Durban, 17 p.
- DU TOIT, A.L. 1920. *The geology of Pondoland and portions of Alfred and Lower Umzimkulu Counties, Natal*. Explanation Sheet 28, (Pondoland), Geological Survey of South Africa, 44 p.

- DU TOIT, A.L. 1931. *The geology of the country surrounding Nkandla, Natal*. Explanation Sheet 109, (Nkandla), Geological Survey of South Africa, 111 p.
- DU TOIT, A.L. 1946. *The geology of parts of Pondoland, East Griqualand and Natal*. Explanation Sheet 119, (Port Shepstone), Geological Survey of South Africa, 32 p.
- DU TOIT, A.L. 1954. *The geology of South Africa, Third Edition*. Edited by S.H. Haughton. Oliver and Boyd, Edinburgh, 611 p.
- DU TOIT, S.R. AND LEITH, M.J. 1974. The J(c)-1 borehole on the Continental shelf near Stanger, Natal. *Transactions of the Geological Society of South Africa* 77: 247-252.
- DUTTA, P.K. 1987. Origin and rarity of first-cycle quartz arenite. *American Association of Petroleum Geologists, Bulletin* 771: 551.
- ERIKSSON, P.G. 1983. A palaeoenvironmental study of the Molteno, Elliot and Clarens Formations in the Natal Drakensberg and northeastern Orange Free State. *Unpublished Ph.D. thesis*, Department of Geology, University of Natal, Pietermaritzburg, 209 p.
- FOLK, R.L. 1976. Reddening of desert sands: Simpson Desert, N.T., Australia. *Journal of Sedimentary Petrology* 46: 604-615.
- FULLER, A.O., 1985. A contribution to the conceptual modelling of pre-Devonian fluvial systems. *Transactions of the Geological Society of South Africa* 88: 189-194. Presidential address.
- GARY, M., McAFEE, R. JNR. AND WOLF, C.L. (Eds.) 1972. *Glossary of geology*. American Geological Institute, Washington, D.C., 857 p.
- GEOLOGICAL SURVEY OF SOUTH AFRICA, 1984. *1:1000 000 Geological Map of the Republics of South Africa, Transkei, Bophuthatswana, Venda and Ciskei, and the Kingdoms of Lesotho and Swaziland*. Government Printer, Pretoria, 4 sheets.
- GEVERS, T.W. 1963. Thermal springs at Lilani, Natal, and their geologic setting. *Transactions of the Geological Society of South Africa* 66: 129-156.
- GHIBAUDO, G., 1992. Subaqueous sediment gravity flow deposits: practical criteria for their field description and classification. *Sedimentology* 39: 423-454.
- GODDARD, E.N., TRASK, P.D., DE FORD, R.K., ROVE, R.N., SINGEWALD, J.T. AND OVERBECK, R.M. 1948. *Rock Colour Chart*. Geological Society of America, U.S.A.
- GRIESBACH, C.L. 1871. On the geology of Natal in South Africa. *Quarterly Journal of the Geological Society of London* 27: 53-72.
- HARDIE, L.A. 1958. The heavy mineral content of the Table Mountain Series of the Cape System, from selected areas in Natal. *Unpublished M.Sc thesis*, University of Natal, Durban, 101 p.
- HARMS, J.C. AND FAHNESTOCK, R.K. 1965. Stratification bed forms and flow phenomena (with an example from the Rio Grande). In: *Primary sedimentation studies and their hydrodynamic interpretation*. (G.V. Middleton, Ed.) Society of Economic Paleontologists and Mineralogists, Tulsa, Oklahoma, (Special Publication No. 12), 84-115.
- HOBDAY, D.K., BRAUTESETH, S.V. AND MATHEW, D. 1971. The Table Mountain Series between the Mtentu River mouth and Waterfall Bluff, Pondoland. *Petros* 3: 51-56.

- HOBDAV, D.K. AND MATHEW, D. 1974. Depositional environment of the Cape Supergroup in the Transkei. *Transactions of the Geological Society of South Africa* 77: 223-227.
- HOBDAV, D.K. AND VON BRUNN, V. 1979. Fluvial sedimentation and paleogeography of an early Paleozoic failed rift, southeastern margin of Africa. *Palaeogeography, Palaeoclimatology, Palaeoecology* 28: 169-184.
- JACOBS, J. 1991. Strukturelle Entwicklung und Abkühlungsgeschichte der Heimetfrontfjella (western Dronning Maud Land). *Berichte zur Polarforschung* 97: 141 p.
- JACOBS, J. AND THOMAS, R.J. 1994. Pan-African rejuvenation of the ~1.1 Ga Natal Metamorphic Province: K-Ar muscovite and sphene fission track evidence. *Proceedings of the International Geological Field Conference (IGCP 348), Arusha, Tanzania*: 76-80.
- JOHNSON, M.R. 1987. *Guidelines for standardised lithostratigraphic descriptions*. South African Committee for Stratigraphy, Circular 1, 18 p.
- JOHNSON, M.R. 1992. A proposed format for general-purpose comprehensive graphic logs. *Sedimentary Geology* 81: 289-298.
- KAHN, J.S. 1956. The analysis and distribution of the properties of packing in sand-sized sediments: 1. On the measurement of packing in sandstones. 2. The distribution of packing measurements and an example of packing analysis. *Journal of Geology* 64: 385-395; 578-606.
- KENT, L.E. 1938. The geology of a portion of Victoria County, Natal. *Transactions of the Geological Society of South Africa* 41: 1-36.
- KING, L.C. AND MAUD, R.M. 1964. *The geology of Durban and environs*. Bulletin of the Geological Survey of South Africa 42: 49 p.
- KINGSLEY, C.S. 1975. A new stratigraphic classification implying a lithofacies change in the Table Mountain Sandstone in southern Natal. *Transactions of the Geological Society of South Africa* 78: 43-55.
- KLEIN, G. de V. 1970. Deposition and dispersal dynamics of intertidal sand bars. *Journal of Sedimentary Petrology* 40: 1095-1127.
- KLEIN, G. de V. 1977. *Clastic tidal facies*. Continuing Education Publication Co., Champaign, Illinois, 149 p.
- KRIGE, L.J. 1933. The geology of Durban. *Transactions of the Geological Society of South Africa* 35: 37-67.
- KRUMBEIN, W.C. AND SLOSS, L.L. 1963. *Stratigraphy and sedimentation*. Freeman and Co., San Francisco, 660 p.
- LAVKULICH, L.M. 1969. Soil dynamics in the interpretation of palaeosols. In: *Pedology and Quaternary Research*. (S. Pawluk, Ed.) National Research Council of Canada, Proceedings of symposium held in Edmonton, Alberta, May 13-14, University of Alberta, 25-37.
- LEWIS, D.W. 1984. *Practical Sedimentology*. Hutchinson and Ross, Stroudberg, Pa., 229 p.
- LOCK, B.E. 1973. The Cape Supergroup in Natal and northern Transkei. *Geological Magazine* 101: 485-486.
- LOURENS, B.D. 1979. Syndepositional structures and penecontemporaneous deformation in the Cape Supergroup to the west of Durban, Natal. Unpublished B.Sc(Hons) thesis, University of Natal, Pietermaritzburg, 76 p.

- LOWE, D.R. 1982. Sediment gravity flows: II Depositional models with special reference to the deposits of high-density turbidity currents. *Journal of Sedimentary Petrology* 52: 0279-0297.
- MARSHALL, C.G.A. 1987. Stratigraphy and sedimentology of the Natal Group in the Inanda Area: Final report on Project RG 85/11. *Unpublished Report*, Geological Survey of South Africa, 28 p.
- MARSHALL, C.G.A. 1988. Stratigraphy and sedimentology of the Natal Group in the Stanger and Eshowe Areas: Final report on Project RG 87/11. *Unpublished Report*, Geological Survey of South Africa, 26 p.
- MARSHALL, C.G.A. 1991 A. Stratigraphy and sedimentology of the Natal Group in the Melmoth and Hlabisa Areas: Final report on Project RG 88/7. *Unpublished report*, Geological Survey of South Africa, 21 p.
- MARSHALL, C.G.A. 1991 B. Stratigraphy and sedimentology of the Natal Group in the Kranskop and Pietermaritzburg Areas: Final report on Project RG 89/6. *Unpublished report*, Geological Survey of South Africa, 17 p.
- MARSHALL, C.G.A. 1991 C. Stratigraphy and sedimentology of the Natal Group in the area between Cato Ridge and Hibberdene: Final report on Project RG 90/6. *Unpublished Report*, Geological Survey of South Africa, 19 p.
- MARSHALL, C.G.A., THOMAS, R.J. AND WATKEYS, M.K. 1991. The Natal Group: Pan-African fluvialite red-beds? *Terra Abstracts, Precambrian Sedimentary Basins of Southern Africa*. Pretoria. *Geological Society of South Africa, Compiled by: P.G. Eriksson: 20 p.*
- MARTIN, A.K. AND HARTNADY, C.J.H., 1986. Plate tectonics development of the southwest Indian Ocean: a revised reconstruction of East Antarctica and Africa. *Journal of Geophysical Research* 91: 4767-4786.
- MARTINI, I.P. AND CHESWORTH, W. 1992. Reflections on soils and paleosols, In: *Weathering, Soils and Paleosols, Developments in Earth Surface Processes 2*. (I.P. Martini and W. Chesworth, Eds), Elsevier, Amsterdam, 3-15.
- MARTINI, J.E.J., 1979. Karst in Black Reef quartzite near Kaapsehoop, Eastern Transvaal. *Annals of the Geological Survey of South Africa* 13: 115-128.
- MATHEW, D. 1971. A palaeoenvironmental study of the basal zone Table Mountain Sandstone at Kloof Gorge. *Petros* 3: 6-17.
- MATTHEWS, P.E. 1961. Slump structures in the Table Mountain Series of Natal. *Transactions of the Geological Society of South Africa* 64: 55-69.
- MATTHEWS, P.E. 1970. Paleorelief and the Dwyka glaciation in the eastern region of South Africa. *Proceedings and Papers, 2nd Gondwana Symposium, International Union of Geological Sciences: 491-499.*
- MATTHEWS, P.E. 1972. Possible Precambrian obduction and plate tectonics in southern Africa. *Nature* 240: 37-39.
- MATTHEWS, P.E. 1988. Breccia sheets and dykes: evidence of hydraulic fracturing in Palaeozoic Natal Group sandstone near Durban, Natal. *Extended Abstract, Gecongress '88, Geological Society of South Africa, Durban, 387-389.*

- Mc BRIDE, E.F. 1963. A classification of common sandstones. *Journal of Sedimentary Petrology* 33: 664-669.
- Mc BRIDE, E.F. 1989. Quartz cement in sandstones: a review. *Earth-Science Reviews* 26: 69-112.
- Mc GOWEN, J.H. AND GROAT, C.G. 1971. *The Van Horn Sandstone, West Texas: an alluvial fan model for mineral exploration*. Bureau of Economic Geology, Report of Investigations No. 72, University of Texas at Austin, 57 p.
- MIALL, A.D. 1977. A review of the braided river depositional environment. *Earth Science Reviews* 13: 1-62.
- MIALL, A.D. 1978. Lithofacies types and vertical profile models in braided rivers: a summary. In: *Fluvial Sedimentology*. (A.D. Miall, Ed) Canadian Society of Petroleum Geologists, Memoir 5, 597-604.
- MIALL, A.D., 1981a. Alluvial sedimentary basins: Tectonic setting and basin architecture. In: *Sedimentation and Tectonics in Alluvial Basins*. (A.D. Miall, Ed.) Geological Association of Canada, Special Paper 23, 1-23
- MIALL, A.D. 1981b. *Analysis of fluvial depositional systems*. American Association of Petroleum Geologists Education Course Notes Series No. 20. 75 p.
- MILLOT, G., RADIER, H., MULLER-FEUGER, R., DEFOSSEZ, Z. AND WEY, R. 1959. Sur la geochemie de la silice et les silicifications Sahariennes. *Bulletin Serv. Carte. Geol. Als. Lorraine* 12: 2.
- MULHOLLAND, H. AND JONES, C.R. 1968. *Fundamentals of statistics*. Butterworths, London, 291 p.
- OKAMOTO, G., OKURA, T. AND GOTO, K. 1957. Properties of silica in water. *Geochimica et Cosmochimica Acta* 12: 123-132.
- PETTIJOHN, F.J. 1975. *Sedimentary Rocks, 3rd Edition*. Harper and Row, New York, 208 p.
- PETTIJOHN, F.J., POTTER, P.E. AND SIEVER, R. 1987. *Sand and sandstones*. Springer Verlag, 553 p.
- PICARD, M.D. AND HIGH, L.J. 1968. Shallow marine currents on the early Triassic Wyoming Shelf. *Journal of Sedimentary Petrology* 38: 411-423.
- PINNA, P., JOURDE, G., CALVEZ, J.Y., MROZ, J.P. AND MARQUES, J.M. 1993. The Mozambique Belt in northern Mozambique: Neoproterozoic (1100 - 850 Ma) crustal growth and tectonogenesis, and superimposed Pan-African (800 - 550 Ma) tectonism. *Precambrian Research* 62: 1-59.
- REDDERING, J.S.V. AND ILLENBERGER, W.K. 1988. Discussion on 'Palaeoenvironmental significance of clast shape in the Nardouw Formation, Cape Supergroup.' *Transactions of the Geological Society of South Africa* 91: 554-555.
- RETALLACK, G., GRANDSTAFF, D. AND KIMBERLEY, M. 1984. The promise and problems of Precambrian paleosols. *Episodes* 7: 8-12.
- RHODES, R.C. AND LEITH, M.J. 1967. Lithostratigraphic zones in the Table Mountain Series of Natal. *Transactions of the Geological Society of South Africa* 70: 15-28.
- RILETT, M.H.P. 1969. On the Patella reported from Kranskop, Natal. *Transactions of the Geological Society of South Africa* 72: 47-48.
- ROBERTS, D.L. 1981. The stratigraphy and sedimentology of the Natal Group in the Durban area. *Unpublished M.Sc thesis, University of Natal, (Durban), 118 p.*

- ROBERTS, D.L. 1990. Marine incursions in the Natal Group, Eustasy or tectonism? *Extended Abstract, Geocongress '90. Geological Society of South Africa, Cape Town, 467-470.*
- RODINE, J.D. AND JOHNSON, A.M. 1976. The ability of debris, heavily freighted with coarse clastic materials, to flow, on gentle slopes. *Sedimentology* 23: 213-234.
- ROWSELL, D.M. 1969. An investigation of some carbonate-bearing sediments of the Cape and Karoo Systems in Natal. *Unpublished M.Sc thesis, University of Natal, 242 p.*
- RUST, B.R. AND JONES, B.G. 1986. The Hawkesbury Sandstone south of Sydney, Australia: Triassic analogue for the deposit of a large, braided river. *Journal of Sedimentary Petrology* 57: 222-233.
- RUST, I.C. 1975. Tectonic and sedimentary framework of Gondwana basins in southern Africa. In: *Gondwana geology*. (K.S. Campbell, Ed.) Australian National University Press, Canberra, 537-564.
- RYAN, P.J., 1967. Stratigraphic and paleocurrent analysis of the Ecca Series and lowermost Beaufort Beds in the Karoo Basin of South Africa. *Unpublished Ph.D. thesis, Faculty of Science, University of Witwatersrand, Johannesburg, 210 p.*
- SCHWARZ, E.H.L. 1917. Notes on the geology of Natal. *Transactions of the Geological Society of South Africa* 19: 46-53.
- SELLEY, R.C. 1982. *An introduction to sedimentology, 2nd Edition*. Academic Press, New York, N.Y., 417p.
- SMITH, G.A. 1986. Coarse-grained non-marine volcanoclastic sediment: Terminology and depositional process. *Geological Society of America Bulletin* 97: 1-10.
- SMITH, N.D. 1970. The braided stream depositional environment: Comparison of the Platte River with some Silurian clastic rocks. *Geological Society of America Bulletin* 81: 2993-3014.
- SOUTH AFRICAN COMMITTEE FOR STRATIGRAPHY (SACS), 1980. *Stratigraphy of South Africa. Part 1: Lithostratigraphy of the Republic of South Africa, South West Africa/Namibia, and the Republics of Bophuthatswana, Transkei, and Venda* (L.E. Kent, comp.). Handbook of the Geological Survey of South Africa, 8, 890 p.
- STRATTEN, T. 1974. Notes on the application of shape parameters to differentiate between beach and river deposits in southern Africa. *Transactions of the Geological Society of South Africa* 77: 59-64.
- SUTHERLAND, P.C. 1868. *On the geology of Natal*. Natural History Association of Natal, 26 p.
- SUTTNER, L.S., BASA, A. AND MACK, G.H. 1981. Climate and origins of quartz arenites. *Journal of Sedimentary Petrology* 51: 1235-1246.
- TANKARD, A.J., JACKSON, M.P.A., ERIKSSON, K.A., HOBDAV, D.K., HUNTER, D.R. AND MINTER, W.E.L., 1982. *Crustal evolution of southern Africa*. Springer-Verlag, New York, 523 p.
- TANNER, L.H. AND HUBERT, J.F. 1991. Basalt breccias and conglomerates in the lower Jurassic Mc Coy Brook Formation, Nova Scotia: differentiation of talus and debris-flow deposits. *Journal of Sedimentary Petrology* 61: 15-27.
- THAMM, A.G., 1988. Author's reply to discussion. *Transactions of the Geological Society of South Africa* 91: 555-556.
- THOMAS, R.J. 1988. *The geology of the Port Shepstone area*. Explanation of Sheet 3030 (Port Shepstone). Geological Survey of South Africa, 136 p.

- THOMAS, R.J., VON BRUNN, V. AND MARSHALL, C.G.A. 1990. A tectono-sedimentary model for the Dwyka Group in southern Natal. *South African Journal of Geology* 93: 809-817.
- THOMAS, R.J., DU PLESSIS, A., FITCH, F.J., MARSHALL, C.G.A., MILLER, J.A., VON BRUNN, V. AND WATKEYS, M.K. 1991. Geological studies in southern Natal and Transkei: Implications for the Cape orogen. In: *Inversion tectonics of the Cape Fold Belt, Karoo and Cretaceous Basins of southern Africa*. (M.J. de Wit and I.G.D. Ransome, Eds.) A.A. Balkema, Rotterdam: 229-236.
- THOMAS, R.J., MARSHALL, C.G.A., WATKEYS, M.K., FITCH, F.J. AND MILLER, J.A. 1992. K-Ar and $^{40}\text{Ar}/^{39}\text{Ar}$ dating of the Natal Group, southeast Africa - a post Pan-African molasse? *Journal of African Earth Sciences* 15: 453-471.
- THOMAS, R.J., VON VEH, M.W. AND MC COURT, S. 1993. The tectonic evolution of southern Africa: an overview. *Journal of African Earth Sciences* 16: 5-24.
- TODD, S.P. 1989. Stream-driven, high-density gravelly traction carpets: possible deposits in the Trabeg Conglomerate Formation, SW Ireland and some theoretical considerations of their origin. *Sedimentology* 36: 513-530.
- TRURNIT, P. 1968. Pressure solution phenomena in detrital rocks. *Sedimentary Geology* 2: 89-114.
- TURNER, B.R. AND WHATELEY, M.K.G. 1983. Structural and sedimentological controls of coal deposition in the Nongoma graben, northern Zululand, South Africa. In: *Special Publication, International Association of Sedimentologists*. (J.D. Collinson and J. Lewin, Eds.) Blackwell Scientific Publications, 457-471.
- VAN STRATEN, O.J. 1953. The geology of the uMlazi area, Natal. *Unpublished M.Sc thesis*, University of Natal, Durban, 31 p.
- VAN VUUREN, C.J. AND COLE, D.I. 1979. The stratigraphy and depositional environments of the Eccia Group in the northern part of the Karoo basin. *Geocongress '77, Geological Society of South Africa, Special Publication 6: 103-111*.
- VISSER, J.N.J. 1974. The Table Mountain Group: a study in the deposition of quartz arenites on a stable shelf. *Transactions of the Geological Society of South Africa* 77: 229-237.
- VISSER, J.N.J., 1990. The age of the late Palaeozoic glaciogene deposits in southern Africa. *South African Journal of Geology* 93: 366-375.
- VON BRUNN, V. 1994. Glaciogenic deposits of the Permo-Carboniferous Dwyka Group in the eastern region of the Karoo Basin, South Africa. In: *Earth's Glacial Record*. (Deynoux, M., Miller, J.M.G., Domack, E.W., Eyles, N., Fairchild, I.J., and Young, G.M. Eds.) Cambridge University Press, 60-69.
- VON BRUNN, V. AND MARSHALL, C.G.A. 1989. Glaciated surfaces and the base of the Dwyka Formation near Pietermaritzburg, Natal. *The South African Journal of Geology* 92: 420-426.
- WALKER, T.R., 1967. Formation of redbeds in ancient and modern deserts. *Geological Society of America Bulletin* 78: 353-368.
- WHITTEN, D.G.A. AND BROOKS, J.R.V. 1972 *The Penguin Dictionary of Geology*. Penguin Books Ltd., England. 493 p.
- WINTER, H. de la R. and VENTER, J.J. 1970. Lithostratigraphic correlations of recent deep boreholes in the Karoo-Cape sequence. *2nd Gondwana Symposium. Proceedings and Papers: 395-408*.
- ZINGG, T. 1935. Beiträge zur Schotteranalyse. Schweiz. Miner. Petrog. Mitt., 15, 38-140.

APPENDICES

The selected measured sections in Appendix 1, the geological maps in Appendix 2, and the shape parameter graphs in Appendix 5, are presented as additional reference data. The contents of Appendices 3 (grain-size and composition data and analysis) and 4 (palaeocurrent data and analysis) are considered essential to the interpretation of the Natal Group and the erection of a stratigraphic subdivision, but they would interrupt the flow of the text, and are thus placed in the appendix also.

APPENDIX 1. MEASURED SECTIONS

Some 151 vertical sections were measured through the Natal Group, covering every stratigraphic unit. The localities are shown in Fig. App-1.1, and listed in Table App-1.1. The sections used in this dissertation (Figs. App-1.3 to App-1.27) follow this page, and are listed in Table App-1.2. The legend for the measured sections is in Fig. App-1.2, while the legend for the lithofacies used is in Table App-1.3.

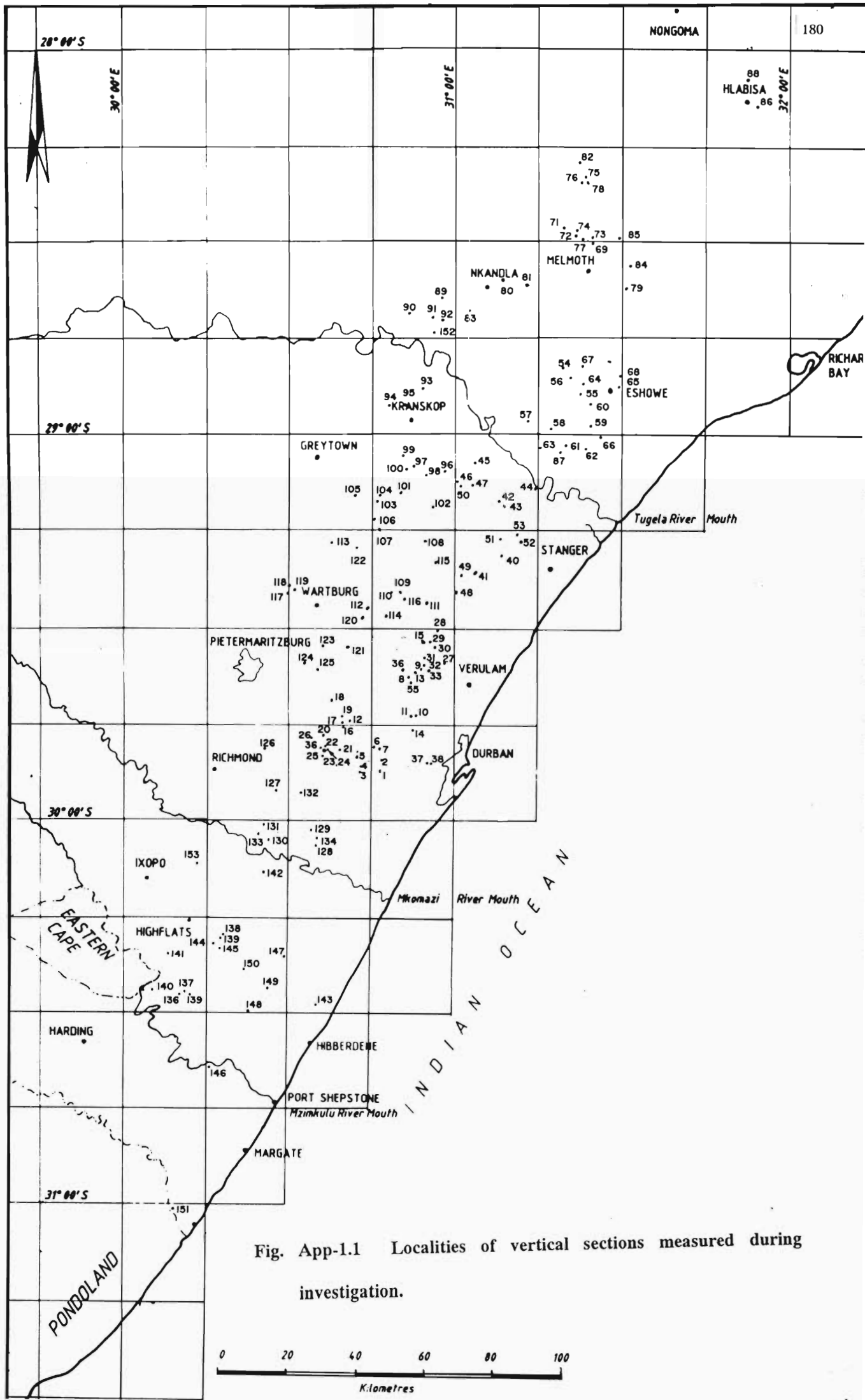


Fig. App-1.1 Localities of vertical sections measured during investigation.

NO.	NAME	GEOREF	LATITUDE	LONGITUDE	ELEV. (m)	LENGTH (m)	STRATIGRAPHY COVERED										
							DURBAN					MARIANNHILL					
							ULUNDI	ESHOWE	K'KLOOF	SITUNDU	D'HOEK	TULINI	M'PAPER	M'VILLE	DWYKA	CAPE S' GRP	
1	Ofudu	2930DD	29 53 00	30 46 35	466	35		*	*								
2	Kwa Ndengezi	2930DD	29 51 30	30 46 50	366	21						*					
3	Khwela	2930DC	29 52 30	30 43 50	390	85			*	*	*		*				
4	Shongweni Ponds	2930DC	29 51 50	30 43 20	390	58			*								
5	Rusticana Ntshongweni	2930DC	29 50 25	30 42 45	540	84		*	*								
6	Assegai Toll	2930DD	29 48 30	30 45 30	549	30				*							
7	Clifton Canyon	2930DD	29 48 40	30 46 30	610	99		*	*	*							
8	Inanda Mountain Road	2930DB	29 37 38	30 51 42	594	119		*	*	*	*						
9	Mdloti S. Bank	2930DB	29 36 35	30 54 20	502	128		*	*	*	*						
10	Molweni A.	2930DB	29 43 38	30 53 09	228	53		*	*								
11	Molweni B.	2930DB	29 43 45	30 52 55	381	172		*	*	*							
12	Monteseel	2930DA	29 44 25	30 41 08	822	70		*	*								
13	Inanda Mt., NE	2930DB	29 36 57	30 53 02	633	39		*	*								
14	Emolweni Kranskloof	2930DD	29 45 45	30 52 30	366	142							*				
15	Ndwedwe	2930DB	29 32 05	30 54 30	655	77		*	*								
16	Nchanga I	2930DC	29 45 10	30 39 55	620	15			*								
17	Nchanga II	2930DA	29 44 50	30 39 55	630	25			*								
18	Nagle Dam Road	2930DA	29 41 08	30 38 07	777	53		*	*								
19	Monteseel W	2930DA	29 44 25	30 41 08	762	64		*	*	*							
20	Georgedale N	2930DC	29 46 14	30 36 38	500	42			*								

Table App-1.1 List of vertical sections measured during study
(Sheet 1 of 8)

NO.	NAME	GEOREF	LATITUDE	LONGITUDE	ELEV. (m)	LENGTH (m)	STRATIGRAPHY COVERED									
							DURBAN FORMATION					MARIANNHILL FORMATION				CAPE S'GRP
							ULUNDI	ESHOWE	K'KLOOF	SITUNDU	D'HOEK	TULINI	N'PAPER	W'VILLE	DWYKA	
21	Hammarsdale Rainbow	2930DC	29 48 48	30 39 27	500	27			*							
22	Mpumalanga Top	2930DC	29 48 16	30 37 09	800	7						*				
23	Mpumalanga A	2930DC	29 48 40	30 36 15	525	17						*				
24	Mpumalanga B	2930DC	29 48 40	30 36 13	525	21						*				
25	Mpumalanga Woodglen	2930DC	29 49 55	30 36 26	640	38						*				
26	Surprise	2930DC	29 47 00	30 34 45	780	135						*				
27	Ogunjini	2930DC	29 35 10	30 58 00	396	60		*	*	*						
28	Kwa Nombhede	2930DB	29 30 18	30 56 58	640	78		*	*							
29	Ndwedwe II	2930DB	29 32 00	30 55 40	597	63		*	*	*	*					
30	Enkwazini	2930DB	29 32 35	30 56 10	494	77		*	*	*						
31	Nhlosane	2930DB	29 34 50	30 54 30	503	17		*	*	*	*					
32	Madunsula	2930DB	29 35 40	30 54 30	442	87		*	*	*	*					
33	Mdloti Gateway	2930DB	29 36 45	30 55 05	533	108		*	*	*						
34	Mtata	2930DB	29 36 45	30 50 50	625	78		*	*	*	*					
35	Maqadini	2930DB	29 38 20	30 51 55	579	105		*	*	*						
36	Mlasi Quarry	2930DC	29 48 40	30 35 30	576	70			*	*	*					
37	Highway Medical Centre	2930DD	29 50 50	30 55 55	183	6								*		
38	Freeway - Westville	2930DD	29 50 40	30 55 45	198	18								*		
39																
40	Glenmill	2931AC	29 18 50	31 8 50	340	165,0		*	*	*						

Table App-1.1 List of vertical sections measured during study
(Sheet 2 of 8)

NO.	NAME	GEOREF	LATITUDE	LONGITUDE	ELEV. (m)	LENGTH (m)	STRATIGRAPHY COVERED										
							DURBAN FORMATION					MARIANNHILL FORMATION					
							ULUNDI	ESHOWE	K'KLOOF	SITUNDU	D'HOEK	TULINI	NEWSPAPER	WESTVILLE	DWYKA	CAPE S' GRP	
41	St. Martins	2931AC	29 21 15	31 4 20	625	33,0		*									
42	Eplangweni	2931AA	29 10 20	31 8 15	600	19,0		*	*								
43	Otomati	2931AA	29 11 20	31 9 05	620	15,0		*									
44	Mvumase	2931AA	29 08 15	31 14 40	230	100,0		*									
45	Mpisi	2931AA	29 04 28	31 03 20	700	18,0		*									
46	Vuma	2931AA	29 07 40	31 00 10	820	67,5		*	*								
47	Sabuyaze	2931AA	29 08 00	31 03 15	861	102,0		*	*								
48	Kemfus Gate	2931AC	29 24 20	31 00 15	670	39,0		*									
49	Isidumbeni	2931AC	29 21 50	31 01 50	701	67,5		*	*								
50	Impumulo	2931AA	29 08 05	31 00 40	950	115,5		*	*	*							
51	Nhlangwini	2931AC	29 16 10	31 08 20	560	87,0			*	*		*					
52	Royden	2931AC	29 16 40	31 12 15	427	15,0							*				
53	Mt. Albert	2931AC	29 15 43	31 11 12	488	20,0							*				
54	Sabuyaze II	2831CD	28 49 10	31 19 30	540	136,5	*	*	*		*	*					
55	Windy Ridge	2831CD	28 53 40	31 22 45	680	26,0							*				
56	Sizabantu	2831CD	28 51 05	31 21 05	750	10,5							*				
57	Mbongolwane	2831CC	28 57 40	31 13 50	808	25,5		*									
58	KuMdluzulu	2831CD	28 59 05	31 17 30	690	60,0		*									
59	KuMagula	2831CD	28 58 58	31 24 25	487	153,0		*									
60	Mehlwane	2831CD	28 55 13	31 24 40	610	96,0							*				

Table App-1.1 List of vertical sections measured during study
(Shcct 3 of 8)

NO.	NAME	GEOREF	LATITUDE	LONGITUDE	ELEV. (m)	LENGTH (m)	STRATIGRAPHY COVERED									
							DURBAN FORMATION					MARIANNHILL FORMATION				
							ULUNDI	ESHOWE	K'KLOOF	SITUNDU	D'ROEK	TULINI	N'PAPER	WESTVILLE	DWYKA	CAPE S' GRP
61	Ekhuphilini	2931AB	29 01 52	31 20 07	533	75,0			*				*			
62	Endulinde	2931AB	29 02 06	31 23 28	472	70,5		*								
63	Ngudwini	2931AB	29 01 51	31 15 16	622	63,0		*								
64	Cloud Hill	2831CD	28 52 00	31 22 56	690	37,5							*			
65	Mlalazi	2831CD	28 52 28	31 29 51	520	143,5		*								
66	Matshemhlope	2931AB	29 00 14	31 26 08	396	105,0		*								
67	Vuma Reform	2831CD	28 40 30	31 23 05	500	143,0	*	*	*	*	*					
68	Nobaqoni	2831CD	28 50 50	31 29 21	450	30,0							*			
69	Boschhoek	2831CB	28 30 10	31 24 41	840	37		*								
70	Tevreden	2831AD	28 29 22	31 22 55	940	9		*								
71	Vlakpoort	2831AD	28 27 30	31 20 11	1040	27							*	*		
72	Tevreden II	2831AD	28 28 28	31 22 00	1020	9								*		
73	Boschhoek II	2831AD	28 30 00	31 24 40	860	17		*								
74	Tevreden III	2831AD	28 28 04	31 22 08	1000	35							*	*		
75	Ndlovana	2831AD	28 19 43	31 23 20	460	8	*									
76	White Mfolozi	2831AD	28 20 18	31 23 00	480	40	*									
77	Tevreden IV	2831AD	28 28 40	31 22 00	1020	9							*	*		
78	Mfolozi East	2831AD	28 20 18	31 23 54	460	20	*									
79	Makasaneni	2831DA	28 37 12	31 30 42	660	96		*								
80	Matshenezimpise	2831CA	28 35 15	31 08 45	1060	74	*	*								

Table App-1.1 List of vertical sections measured during study
(Sheet 4 of 8)

NO.	NAME	GEOREF	LATITUDE	LONGITUDE	ELEV. (m)	LENGTH (m)	STRATIGRAPHY COVERED									
							DURBAN FORMATION					MARIANHHILL FORMATION				
							ULUNDI		K'KLOOF	SITUNDU	D'BOEK	TULINI	N'PAPER	WESTVILLE	DWYKA	CAPE S' GRP
81	Vinqu	2831CA	28 36 57	31 13 05	920	75		*	*			*				
82	Loliwe	2831AD	28 17 10	31 22 40	600	33	*	*								
83	Ndindinde	2831CA	28 40 50	31 02 40	805	46	*	*								
84	Nungwini	2831DA	28 33 30	31 31 40	551	92	*	*								
85	Morgenzon	2831AD	28 29 10	31 29 30	660	24						*				
86	Kwaseme	2831BB	28 08 21	31 54 30	580	40						*				
87	Dunayo	2931AB	29 02 20	31 19 05	565	12		*	*	*						
88	Nzimane	2831BB	28 04 45	31 52 40	590	99	*	*			*	*				
89	Nsuze	2830DB	28 38 46	39 57 45	823	42	*								*	
90	Mfongosi	2830DB	28 41 15	30 51 55	812	22	*	*							*	
91	Dolwana	2830DB	28 41 54	39 56 07	884	47	*									
92	Dolwana East	2839DB	28 42 04	30 57 53	869	51	*	*							*	
93	Ka-Gonitshe	2830DD	28 52 42	30 54 21	996	105		*	*	*		*	*		*	
94	Klein Doornhoek	2830DD	28 55 10	30 48 29	1113	15		*								
95	Spekfontein	2830DD	28 55 16	30 51 20	945	61		*	*	*	*	*	*		*	
96	Silverstream	2930BB	29 05 45	30 58 23	945	10		*								
97	Tulini II	2930BB	29 05 05	30 52 52	1051	4		*								
98	Tulini	2930BB	29 06 12	30 55 00	920	48		*	*	*		*	*			
99	Hlimbitwa	2930BB	29 03 20	30 50 50	1128	86		*	*	*		*				
100	Lilane	2930BB	29 05 20	30 51 20	1021	55		*	*							

Table App-1.1 List of vertical sections measured during study
(Sheet 5 of 8)

NO.	NAME	GEOREF	LATITUDE	LONGITUDE	ELEV. (m)	LENGTH (m)	STRATIGRAPHY COVERED									
							DURBAN FORMATION					MARIANNHILL FORMATION				
							ULUNDI	ESHOWE	K'KLOOF	SITUNDU	D'BOEK	TULINI	N'PAPE R	WESTVILLE	DWYKA	CAPE S' GRP
101	Matimatolo	2930BB	29 08 58	30 50 40	1097	51		*	*	*		*				
102	Mshayonyoni	2930BB	29 11 21	30 56 03	930	60		*	*							
103	Kwa Mbula	2930BB	29 10 47	30 46 01	1113	74		*	*							
104	Mabovini	2930BB	29 09 50	30 46 38	1143	55		*	*							
105	Baviaanskrans	2930BA	29 09 38	30 42 07	1051	75		*	*		*	*				
106	Carney Hill	2939BB	29 13 12	30 45 02	965	82		*	*	*		*				
107	Tweefontein	2930BB	29 15 00	30 46 37	780	59		*	*		*					
108	Tsheni	2930BD	29 16 15	30 54 18	950	100		*	*							
109	Kingscliffe	2930BB	29 24 13	30 51 12	1000	80		*	*							
110	Clantrock	2930BD	29 25 09	30 47 17	1000	5,5					*					
111	Ntabasikobho	2930BD	29 26 06	30 55 18	700	5,5		*								
112	Killiekrankie	2930BC	29 26 58	30 44 37	880	8					*					
113	Ekamanzi	2930BC	29 16 48	30 37 55	960	11,5					*					
114	Nsinizini	2930BD	29 27 53	30 48 05	900	67		*	*			*				
115	Ngcongcongonga	2930BD	29 20 56	30 56 37	780	139			*	*		*	*			
116	Noodsberg	2930BD	29 25 12	30 51 00	1000	88,5		*	*							
117	Camelhoek	2930BC	29 24 20	30 30 10	720	45		*	*		*	*				
118	Camelhoek North	2930BC	29 23 38	30 30 40	720	13,5		*	*							
119	Sherbrook	2930BC	29 24 08	30 31 08	760	52,5		*	*	*	*					
120	Kwa Gcumagcuma	2930BC	29 27 52	39 43 45	940	32			*	*	*	*				

Table App-1.1 List of vertical sections measured during study
(Sheet 6 of 8)

NO.	NAME	GEOREF	LATITUDE	LONGITUDE	ELEV. (m)	LENGTH (m)	STRATIGRAPHY COVERED									
							DURBAN FORMATION					MARIANNHILL FORMATION				
							ULUNDI	ESHOWE	K'KLOOF	SITUNDU	D'BOEK	TULINI	N'PAPER	WESTVILL E	DWYKA	CAPE S' GRP
121	Odlameni	2930DA	29 32 55	30 41 05	877	77		*	*	*	*					
122	Boekenhoutfontein	2930BC	29 17 12	30 42 50	880	72		*	*			*	*			
123	Mkabela	2930DA	29 32 26	30 36 22	840	35			*							
124	Goedverwachting	2930DA	29 35 11	30 33 19	730	7,5		*							*	
125	Table Mountain	2930DA	29 35 50	30 35 42	945	68,5		*	*						*	
126	Misty Vale	2930CD	29 48 20	30 25 53	870	54		*	*							
127	Strathfieldsaye	2930CD	29 54 59	30 27 52	880	30		*								
128	Ngilanyoni	3030BA	30 03 53	30 35 10	609	15				*						
129	Mount Langford	3030BA	30 01 05	30 34 26	762	46		*	*							
130	Nhlazuka	3030AB	30 02 29	30 26 53	963	48		*	*							
131	Zikumkele	3030AB	30 00 40	30 25 42	670	99						*				
132	Mgwahumbe	2930DC	29 55 27	30 32 46	635	15							*			
133	Nkumane	3030AB	30 02 20	30 24 25	853	19,5						*				
134	Mkongoma	3030BA	30 02 40	30 35 42	701	36		*								
135	Mahlabatshane	3030AC	30 27 13	30 12 14	610	39		*	*			*			*	
136	Inkwazi	3030AC	30 27 04	30 10 39	640	31		*	*							
137	Ntabakucasha	3030AC	30 26 36	30 11 46	686	35	*	*	*						*	
138	Hlutankungu	3030AD	30 17 33	30 18 16	1021	28			*							
139	Mtwalume	3030AD	30 18 21	30 17 56	930	61,5		*	*							
140	Mzinkulu	3030AC	30 26 09	30 05 24	625	39		*	*						*	

Table App-1.1 List of vertical sections measured during study
(Sheet 7 of 8)

NO.	NAME	GEOREF	LATITUDE	LONGITUDE	ELEV. (m)	LENGTH (m)	STRATIGRAPHY COVERED									
							DURBAN FORMATION					MARIANHEILL FORMATION				CAPE S' GRP
							ULUNDI	ESHOWE	K'KLOOF	SITUNDU	D'HOEK	TULINI	N'PAPER	WESTVILLE	DWYKA	
141	Black's Store	3030AC	30 20 16	30 08 27	777	21	*	*							*	
142	Mkunya	3030AB	30 07 45	30 25 25	853	82,5		*	*	*	*					
143	Mtwalume East	3030BC	30 28 15	30 35 50	30	120		*	*	*	*					
144	Ngcobeni	3030AD	30 18 44	30 16 30	914	56		*	*	*						
145	Igoxa	3030AD	30 19 35	30 17 40	945	65	*	*	*	*						
146	Gibraltar	3030CB	30 38 25	30 15 42	480	75										*
147	Mbiyane	3030AD	30 21 55	30 29 12	488	105		*	*	*	*					
148	Odeke	3030AD	30 29 45	30 22 30	640	37,5		*	*							
149	Pulunjani	3030AD	30 25 19	30 26 37	557	72,5	*	*	*							
150	Mkombela	3030AD	30 22 52	30 21 50	732	28,5		*	*							
151	Mtamvuna Nat. Res.	3130AA	31 00 42	30 08 46	381	305										*
152	Macala	2830DB	28 44 25	30 56 50	914	12,0	*									*
153	Nhlavini	3030AA	30 06 32	30 13 53	732	153						*			*	

Table App-1.1 List of vertical sections measured during study
(Sheet 8 of 8)

LITHOLOGY AND CONTACTS

	Diamictite
	Dolerite
	Shale, mudstone
	Siltstone
	Sandstone; = conglomeratic
	Granulestone
	Conglomerate

clast-supported

	matrix-supported
	Alternating lithologies
	no outcrop
	economy break

	Gradational contact
	Sharp contact
	Erosional contact
	Faulted contact

STRUCTURES

	Planar cross-bedding
	Trough cross-bedding
	Foreset dip of 15° in direction 275°
	Horizontal lamination
	Crude stratification
	No visible structures
	Current ripple-marks
	Lenticular litho-unit
	Lenticular bed
	Lenticular bedding
	Concretion, carbonate, iron, etc.
	Rip-up (intraformational) clast
	Soft-sediment deformation
	Reactivation surface
	Graded foresets
	Bedding dips 8° in direction 95°
	Varves

COLOUR

CODE

6,7,8

4,5

2,3

COLOURS

1

2



very pale

pale

medium

dark

1 = weathered

2 = unweathered

l

r

l = left-hand column

r = right-hand column

5R 4/2 = Munsell colour code

ADDITIONAL DATA

Maximum clast diameter, mm

Rounded

Sub-angular to sub-rounded

Angular

Silicified

Ferruginous cement

Muddy, silty

ABBREVIATIONS

n	mean (clast diam.in mm, azimuth in degrees etc.)
SD	population size
CPD	Standard deviation
—	Clast Packing Density, %
—	Well, very (e.g. <u>S</u> rt = well-sorted, <u>c</u> = very coarse)
()	Very well, very highly etc.
(())	Slight, poor
fsp	Very slight, very poor
mic	Feldspathic
Sil	Micaceous
fe	Siliceous, silicified
f	Ferruginous
c	Fine
m	Coarse
qtz	Medium
qtzte	Quartz
SS	Quartzite
Silts	Sandstone
Sh	Siltstone
congl	Shale
argil	Conglomerate, conglomeratic
<	Argillaceous
>	Less than ...
Srt.	Greater than ...
	Sorted

BED THICKNESS

Appropriate column filled in

l

c

r

l = left column lithology

c = centre column lithology

r = right column lithology

GRAINSIZES

Average grain-size indicated by right hand margin

Two fractions of bimodal sediment

Two fractions of closely-alternating grain-sizes

Three fractions of closely-alternating grain-sizes

Three fractions in which one fraction rapidly alternates with a bimodal lithology

Fig. App-1.2 Symbols and abbreviations used in measured sections.

UNITS	NATAL GROUP		1: 100	P. 1 of 1
LOCALITY	Assegai Toll		HGT	549 m
LOGGED BY	C.G.A. Marshall		19-11-1986	

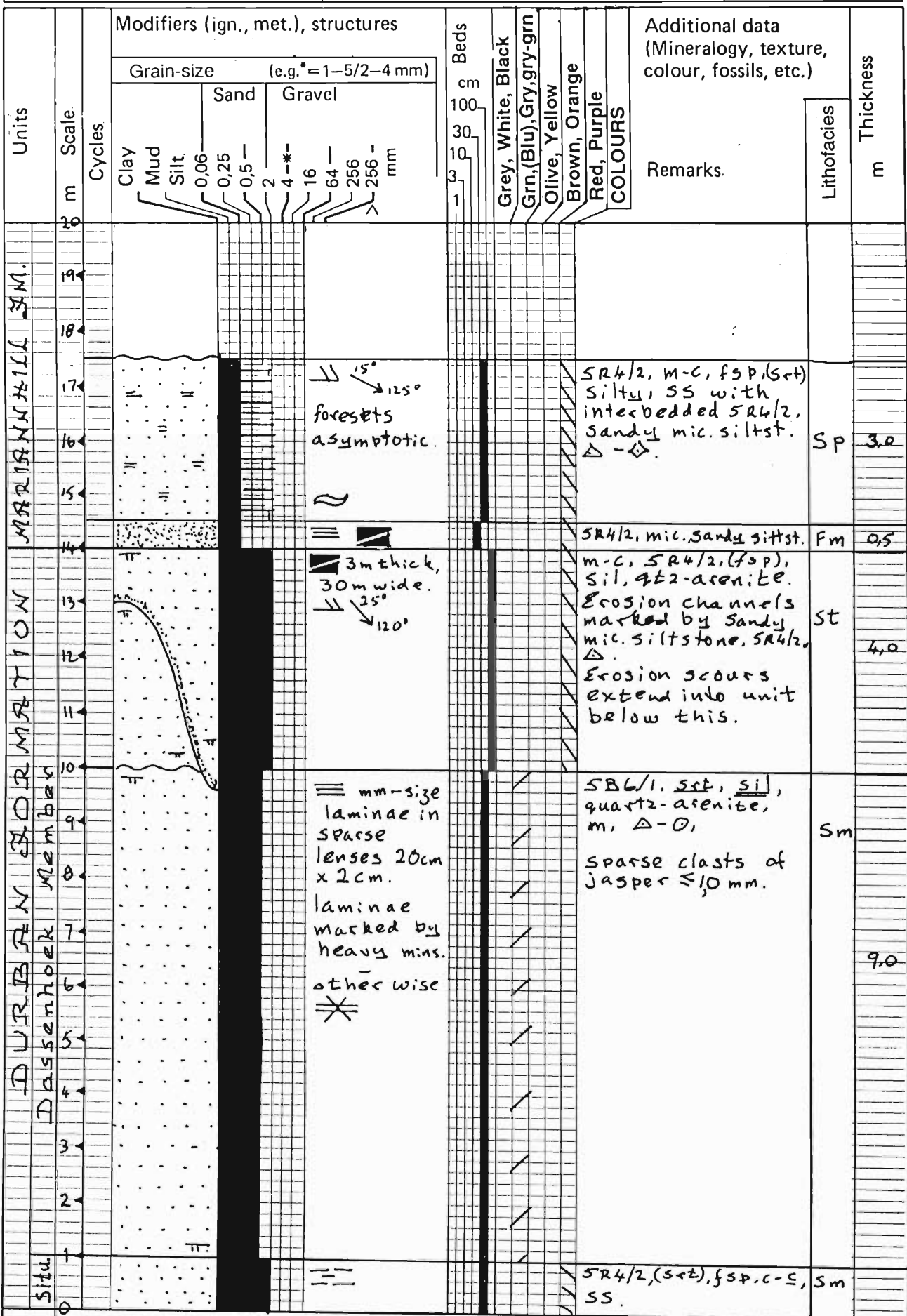


Fig. App-1.3 Measured Section 6 - Assegai Toll

UNITS	NATAL GROUP	1: 200	P.1 of 2
LOCALITY	Nhlangwini	HGT	560 m
LOGGED BY	C.G.A. Marshall	27-03-1987	

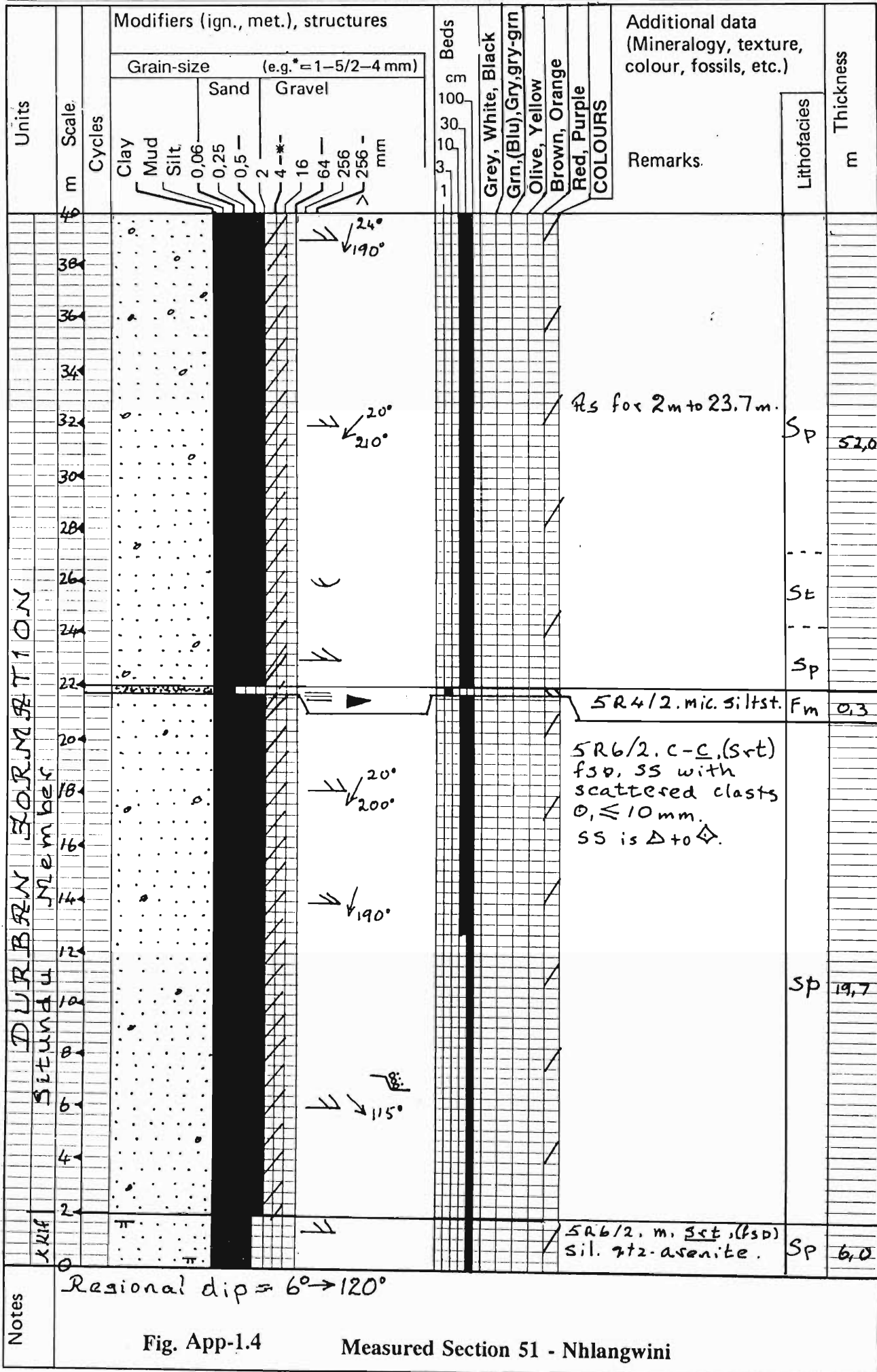


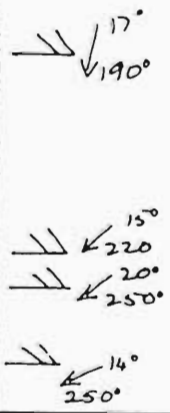
Fig. App-1.4 Measured Section 51 - Nhlangwini

UNITS	NATAL GROUP	1: 200	P. 2 of 2
LOCALITY	Nhlangwini	HGT	560 m
LOGGED BY	C.G.A. Marshall	27-03-1987	

Units	m	Cycles	Modifiers (ign., met.), structures		Beds cm	COLOURS	Additional data (Mineralogy, texture, colour, fossils, etc.)	Lithofacies	Thickness m
			Grain-size (e.g. * = 1-5/2-4 mm)						
			Clay	Sand					
			Clay Mud. Silt. 0,06 0,25 0,5 2 4 - *	Sand 16 64 256 256 - >	Gravel mm		Grey, White, Black Grn.(Blu), Gry, gry-grn Olive, Yellow Brown, Orange Red, Purple	Remarks	
MARRIENHILL SM. Newspaper Member.	80								
	78								
	76								
	74								
	72								
DURBAN FORMATION Situndu Member	54								
	52								
	50								
	48								
	46								
	44								
	42								
	40								
Notes									

As below, but
 ≤ 60 mm,
 CPD ~ 5%.

As below.



Gms

Sp.

90

UNITS	NATAL GROUP	1: 100	P.1 of 2
LOCALITY	Vuma Reform	HGT	500 m
LOGGED BY	C.G.A. Marshall	B - 7 - 1987	

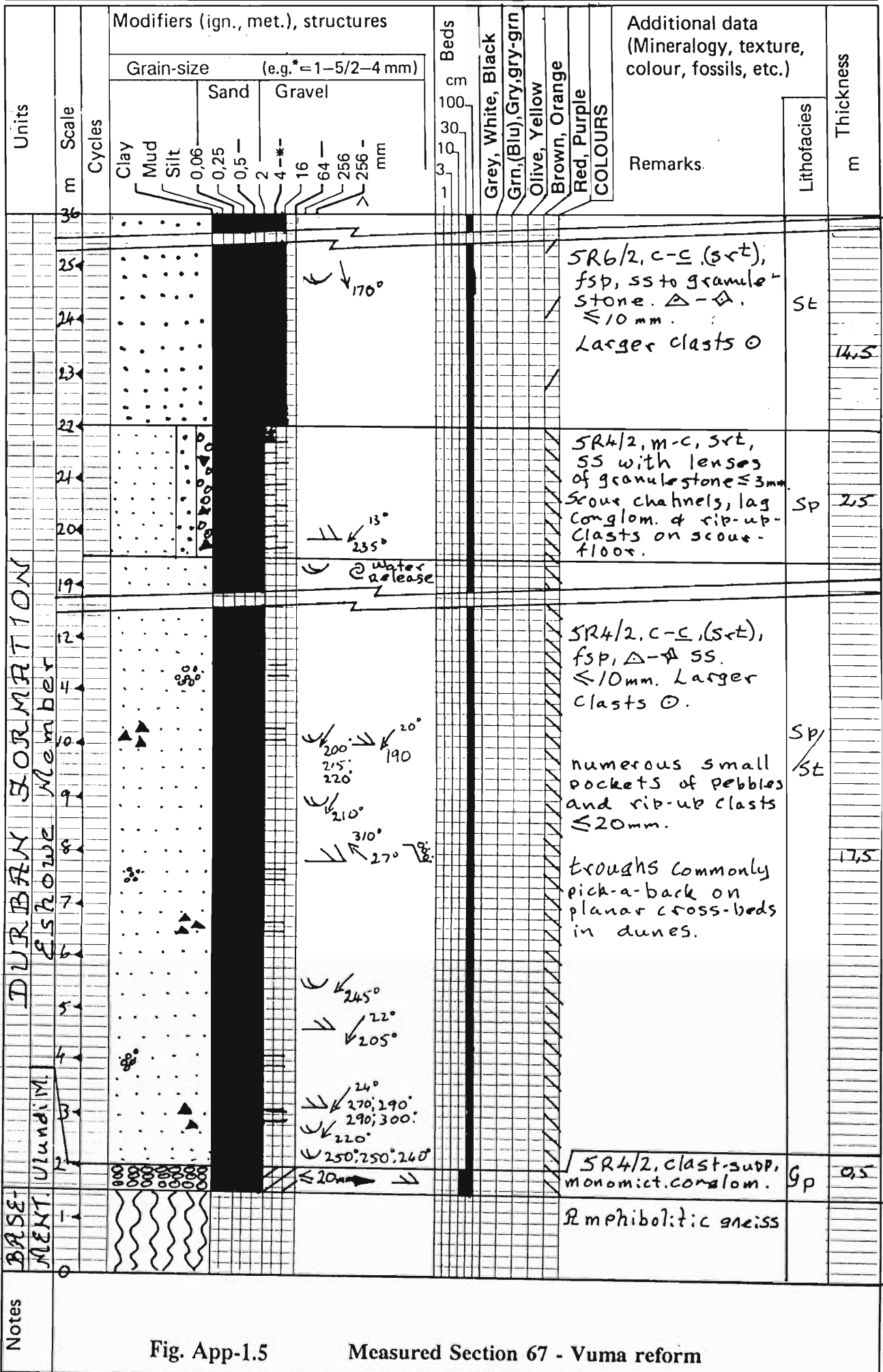


Fig. App-1.5

Measured Section 67 - Vuma reform

UNITS	NATAL GROUP	1: 100	P. 2 of 2
LOCALITY	Vuma Reform.	HGT	500 m
LOGGED BY	C.G.A. Marshall	8-7-1987.	

Units	m Scale	Cycles	Modifiers (ign., met.), structures		Beds	cm	Grey, White, Black Grn.(Blu), Gry, gry-grn Olive, Yellow Brown, Orange Red, Purple COLOURS	Additional data (Mineralogy, texture, colour, fossils, etc.)	Remarks	Lithofacies	Thickness m
			Grain-size (e.g.*=1-5/2-4 mm)								
			Clay Mud Silt 0.06 0.25 0.5 - 2 4 -* 16 64 256 > 256 - mm	Sand Gravel							
DURBAN FORMATION Kranskloof Member.											
	36										
	37										
	38										
ESHOWE M.	39								SR6/2, m-c. (fsp), sst, sil. quartz- arenite.	Sm	1.7
	40								SR6/2, c-c, fsp, (set), Δ-Δ, ss to granulstone. ≤ 10mm. Larger clasts Ø.	St	2.0
Notes	41								SR4/2, f. Silty, mic. ss.	Sm	0.3
	42								As below.		

scouring.

SR4/2, m-c. (fsp),
sst, sil. quartz-
arenite.

SR6/2, c-c, fsp,
(set), Δ-Δ, ss to
granulstone.
≤ 10mm. Larger
clasts Ø.

SR4/2, f. Silty, mic.
ss.

As below.

UNITS	NATAL GROUP	1: 50	P. 1 of 1
LOCALITY	Tevreden II	HGT	1020 m
LOGGED BY	C.G.A. Marshall	20-04-1988	

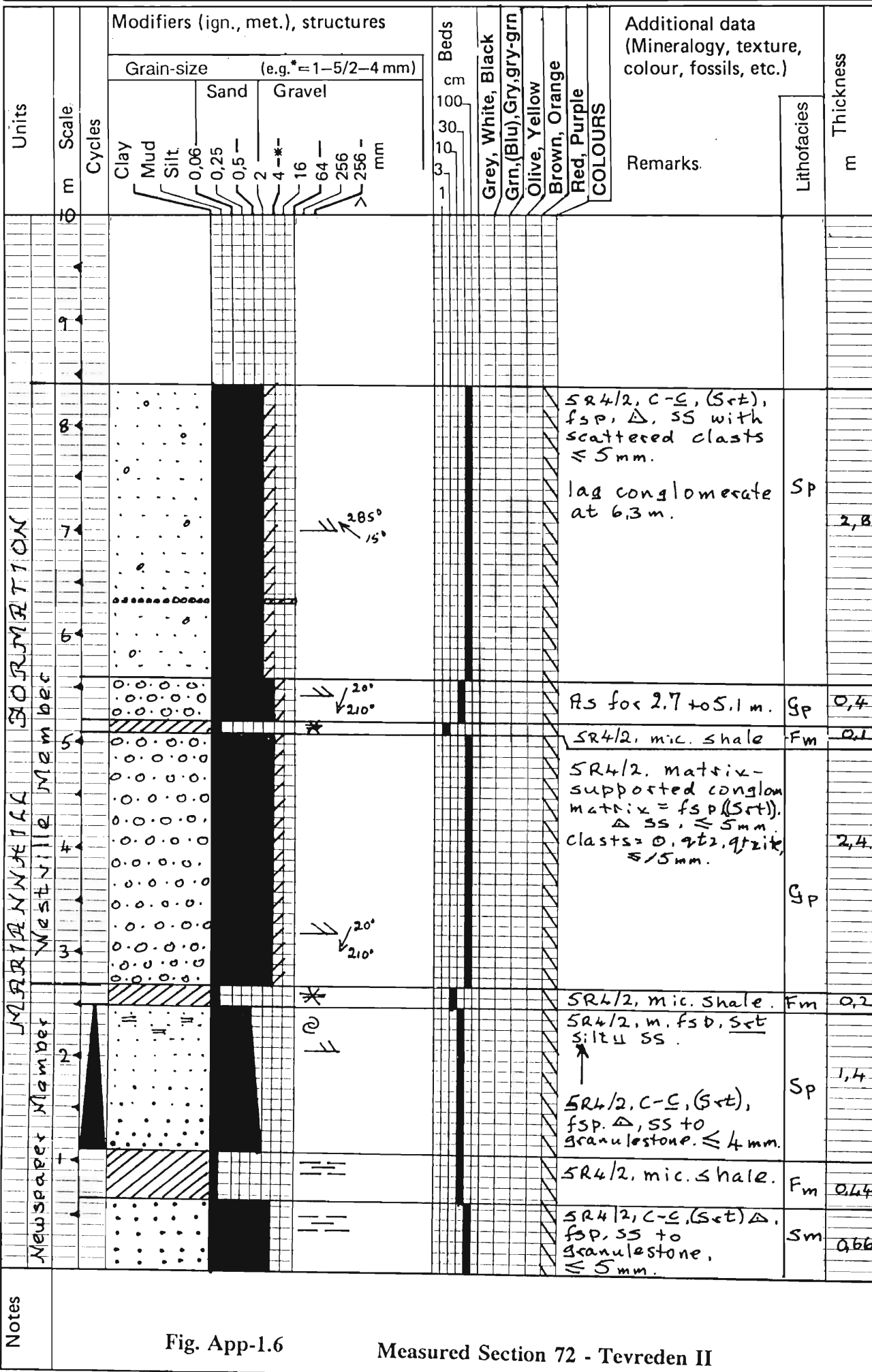
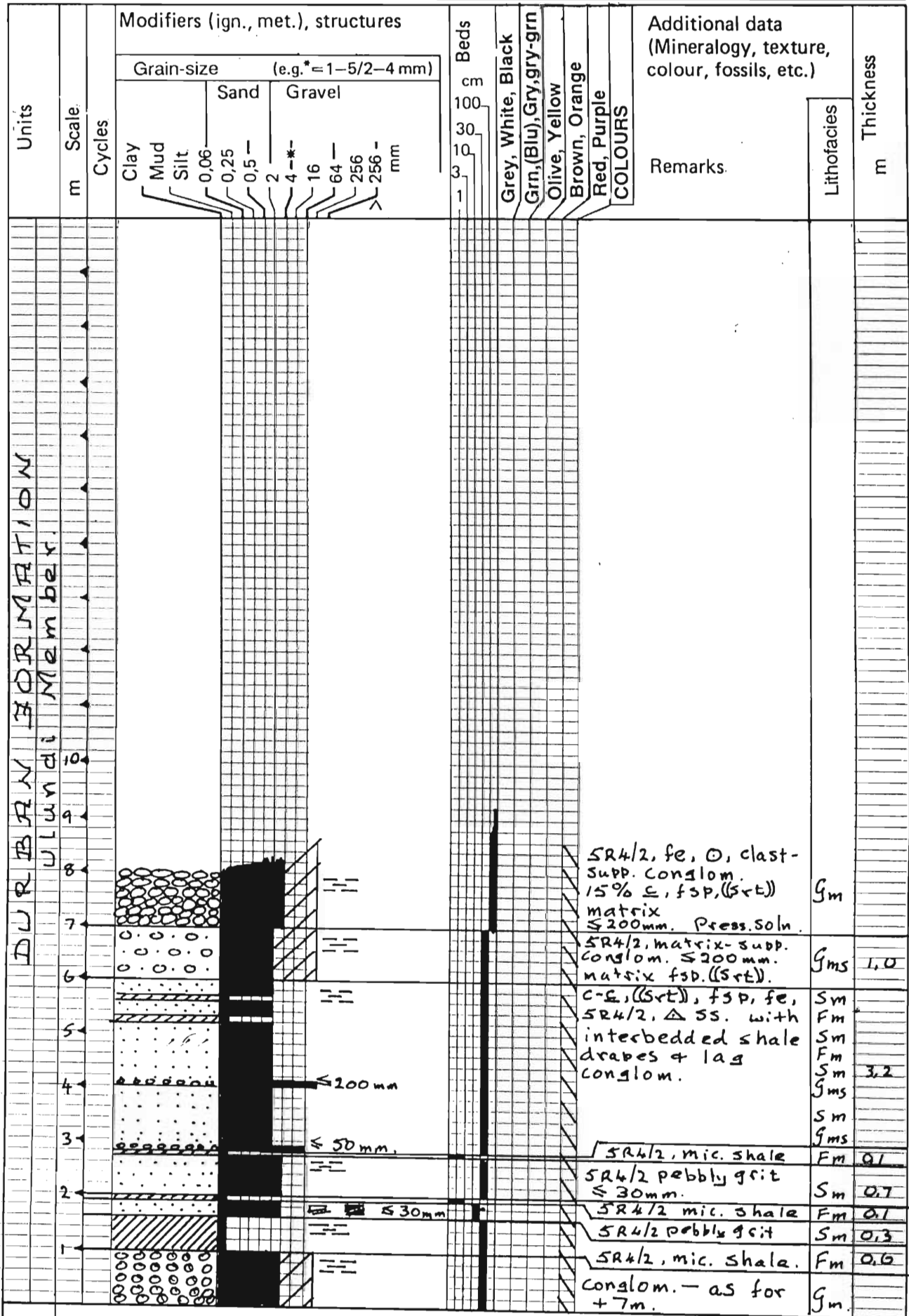


Fig. App-1.6

Measured Section 72 - Tevreden II

UNITS	NATAL GROUP	1: 100	P. 1 of 1
LOCALITY	Ndlovana	HGT	460 m
LOGGED BY	C.G.A. Marshall	11-05-1988	



Notes

Fig. App-1.7 Measured Section 75 - Ndlovana

UNITS	NATAL GROUP	1: 100	P.1 of 3
LOCALITY	White Mfolozi	HGT	480 m
LOGGED BY	C.G.A. Marshall	17-05-1988	

Units	Scale m	Cycles	Modifiers (ign., met.), structures		Beds cm	Lithofacies	Thickness m				
			Grain-size (e.g.*=1-5/2-4 mm)					Remarks			
			Clay	Sand					Gravel		
			Clay Mud Silt 0.06 0.25 0.5 -	2 4 - * 16 64 256 > 256 - mm							
						Grey, White, Black Grn.(Blu), Gry, gry-grn Olive, Yellow Brown, Orange Red, Purple COLOURS	Additional data (Mineralogy, texture, colour, fossils, etc.)				
FORMATION	Member	31					SR = 87 mm SD = 66 mm NS = 38 NS = 300 mm.	As Above	Gm	1.4	
		30					SR 4/2 siltstone		Fm	0.02	
		29					SR = 72 mm SD = 46 mm NS = 101 NS = 220 mm	SR 4/2, clast- supp. O with c-c, fsp, fe, (Set), Δ	Gm		
		28									
		27									
		26									
		25						SR = 50 mm SD = 28 mm NS = 24 NS = 100 mm.	SR 4/2 silty matrix. Press.Soln.	Gm	1.0
		24						SR 4/2, silty, c-c, Δ (Set)		Gm	0.3
		23						SR = 75 mm SD = 63 mm NS = 64 NS = 260 mm	SR 4/2, clast-supp. O, (Set) with silty SS matrix. c-c, fsp, (Set) Δ, SR 4/2.	Gm	2.4
		22						SR = 132 mm SD = 22 mm NS = 12 NS = 250 mm	Press.Soln.		0.8
21						SR = 51 mm SD = 41 mm NS = 90 NS = 230 mm			2.2		
DWARBAN	Wundi	6						Inaccessible			
		5						cliff, ...			
		4						SR = 69 mm SD = 54 mm NS = 28 NS = 100 mm	SR 4/2, clast-supp. O, (Set), Matrix is silty, c-c, fsp, (Set), Δ, SR 4/2, SS.	Gm	1.5
		3						SR = 42 mm SD = 38 mm NS = 15 NS = 190 mm			1.9
		2						SR = 46 mm SD = 67 mm NS = 26 NS = 350 mm	Many clasts have pressure- solution hollows.		2.6
		1									
								Basement.			
Notes	Dip is 15° in direction 140°		Overall Clast Sizes		SR = 75 mm	SD = 56 mm	NS = 520	NS = 500 mm	ΣX = 3900		

Fig. App-1.8 Measured Section 76+78 - White Mfolozi

UNITS	NATAL GROUP	1: 100	P.2 of 3
LOCALITY	White Mfolozi	HGT	480 m
LOGGED BY	C.G.A. Marshall		17-05-1988

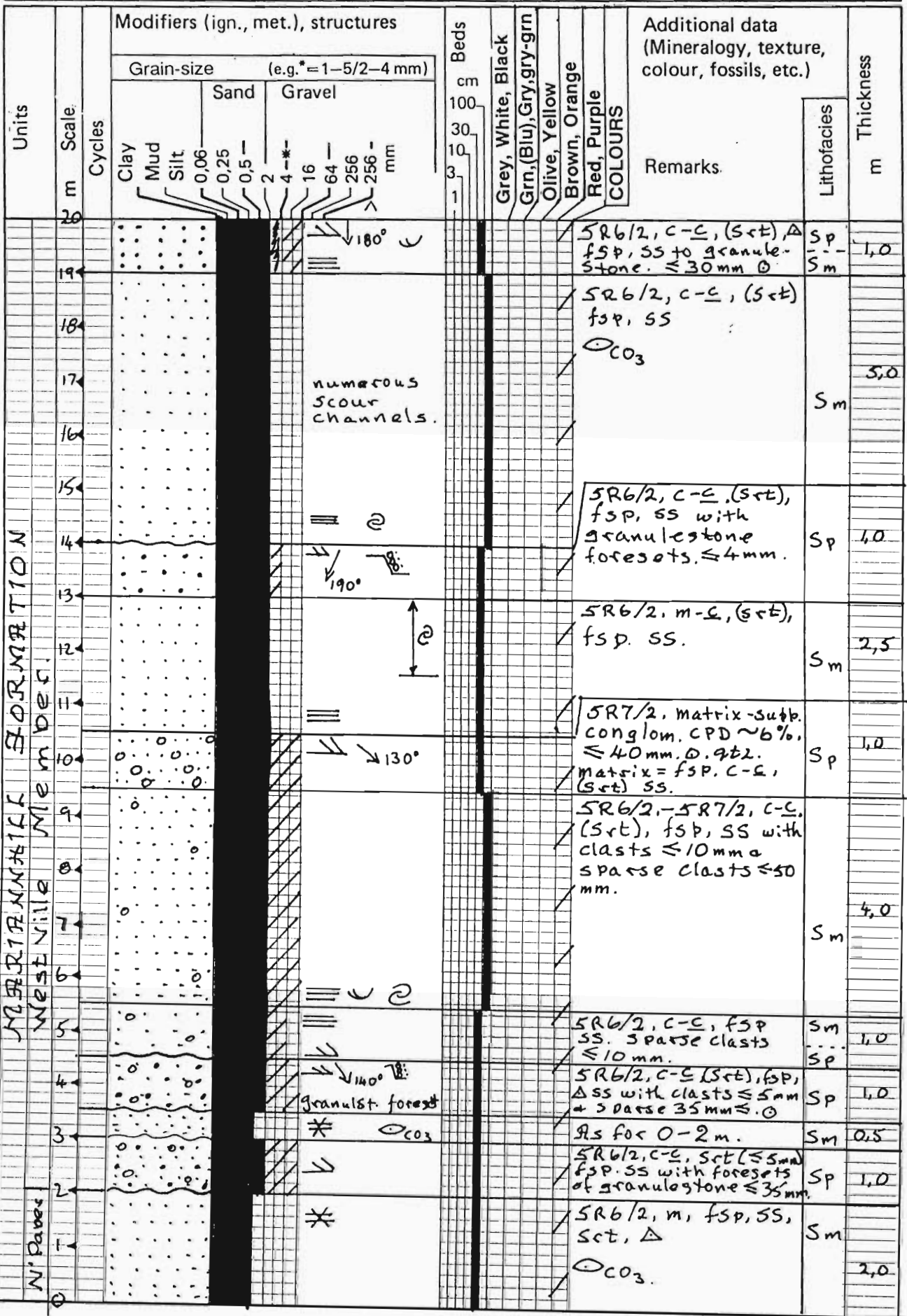
Units	Scale m	Cycles	Modifiers (ign., met.), structures		Beds cm	COLOURS	Additional data (Mineralogy, texture, colour, fossils, etc.)	Lithofacies	Thickness m	
			Grain-size (e.g.*=1-5/2-4 mm)							Remarks
			Clay Mud Silt 0.06 0.25 0.5	Sand Gravel 2 4- 16 64 256 >256 mm						
DURBAN WINDI MEMBER	38					SR4/2, fsp, c-e, (srt)	Sm	0.2		
	39					SR4/2, O, (srt), clast-supp. silt. Ferr. ss, mat	Gm	0.8		
	40					SR = 91mm SD = 63mm N = 24 K = 300mm	Gm	1.7		
	41					SR = 88mm SD = 49mm N = 32 K = 270mm	Gm	1.8		
	42					SR4/2, c-e (srt), fsp, Δ	Fm	0.2		
	43					SR4/2, matrix-supp. silty ss matrix ≤ 200	Gms	0.5		
	44					c-c (srt), fsp, Δ, SR6/2.	Sm			
	45							6.0		
	46									
	47									
	48									
	49									
	50									
	51									
	52									
53										
54										
55										
56										
57										
58										
59										
60										
61										
62										
63										
64										
65										
66										
67										
68										
69										
70										
71										
72										
73										
74										
75										
76										
77										
78										
79										
80										
81										
82										
83										
84										
85										
86										
87										
88										
89										
90										
91										
92										
93										
94										
95										
96										
97										
98										
99										
100										
Notes										

UNITS	NATAL GROUP	1:50	P.1 of 1
LOCALITY	Tevreden IV	HGT	1020 m
LOGGED BY	C.G.A. Marshall	26-05-1988.	

Units	Scale m	Modifiers (ign., met.), structures		Beds cm	COLOURS	Additional data (Mineralogy, texture, colour, fossils, etc.)	Lithofacies	Thickness m	
		Grain-size (e.g.*=1-5/2-4 mm)							Remarks.
		Clay	Sand						
		Clay Mud Silt 0.06 0.25 0.5 -	Sand 2 4 -*	Gravel 16 64 256 256 - mm	Grey, White, Black Grn.(Blu),Gry,gry-grn Olive, Yellow Brown, Orange Red, Purple				
MARBLENHILL FORMATION Westville Member	10								
	9								
	8			10° 100		SR4/2, c-c, fsp, Δ, SS with granulestone foresets.	Sp	1.5	
	7			15° 195		SR4/2, c-c, (set), fsp, SS to granulestone with common clasts, D. ≤ 30mm.	Sp	0.8	
	6			15 200 lac congloms.		SR4/2, mic. shale.	Fm	0.7	
	5					SR4/2, c-c, fsp, Δ, set, SS.	St	0.8	
	4			15° 180		SR4/2, fsp (set), Δ granulestone. ≤ 8mm.	Sp	0.2	
	3					SR4/2, mic. shale	Fm	0.2	
	2			15° 165		SR4/2, c, fsp, set, Δ, SS	Sm	0.3	
	1			20° 170		SR4/2, c-c, (set), fsp, Δ SS to granulestone. ≤ 10mm Ø.	Sp	0.9	
Newspaper M.	0								
	1			20° 100		SR6/2, matrix-supp. conglom. matrix is SR6/2, fsp, (set) granulestone.	Sms	0.7	
	2			15° 105		SR6/2, c-c, (set), Δ fsp, SS to granuleston. ≤ 20mm Ø.	Sm	0.45	
	3			15° 175		SR7/2, c-c, (set) Δ fsp, SS to granulestone. ≤ 20mm Ø.	Sp	0.05	
Notes									

Fig. App-1.9 Measured Section 77 - Tevreden IV

UNITS	NATAL GROUP	1: 100	P. 1 of 2
LOCALITY	Kwaseme	HGT	580 m
LOGGED BY	C.G.A. Marshall	25-08-1988	



Notes
 Fig. App-1.10 Measured Section 86 - Kwaseme

Units	Scale m	Cycles	Modifiers (ign., met.), structures				Beds cm	COLOURS	Additional data (Mineralogy, texture, colour, fossils, etc.)	Lithofacies	Thickness m	
			Grain-size (e.g. * = 1-5/2-4 mm)		Sand	Gravel						Remarks
			Clay	Mud Silt								
			0.06 0.25 0.5 2 4 16 64 256 > 256 - mm	0.06 0.25 0.5 2 4 16 64 256 > 256 - mm		3 10 30 100 cm	Grey, White, Black Grn.(Blu), Gry, gry-grn Olive, Yellow Brown, Orange Red, Purple					
Dwyske Group												
	36							SR6/2, f. diamictite		>100		
	35							10YR 8/2, varved shale	Fsc	0.5		
	34							SR6/2, fine diamictite	Gms	1.0		
	33							SR6/2, massive hard mudstone.	Fsc	0.3		
Major Tertiary Formation								SR6/2, c-c, (set), fsp. ss. with scattered clasts of qtz, chert & jasper, 0. ≤ 20mm	Sp			
Westville Member								Authigenic pyrite cubes. ~10mm side.		14.2		
	24								Sm			
	22								Sm Sm St			
	21							Numerous scours.				

Notes



UNITS	NATAL GROUP	1: 100	P. 1 of 4
LOCALITY	Nzimbabwe	HGT	590 m
LOGGED BY	C.G.A. Marshall	31-8-1988	

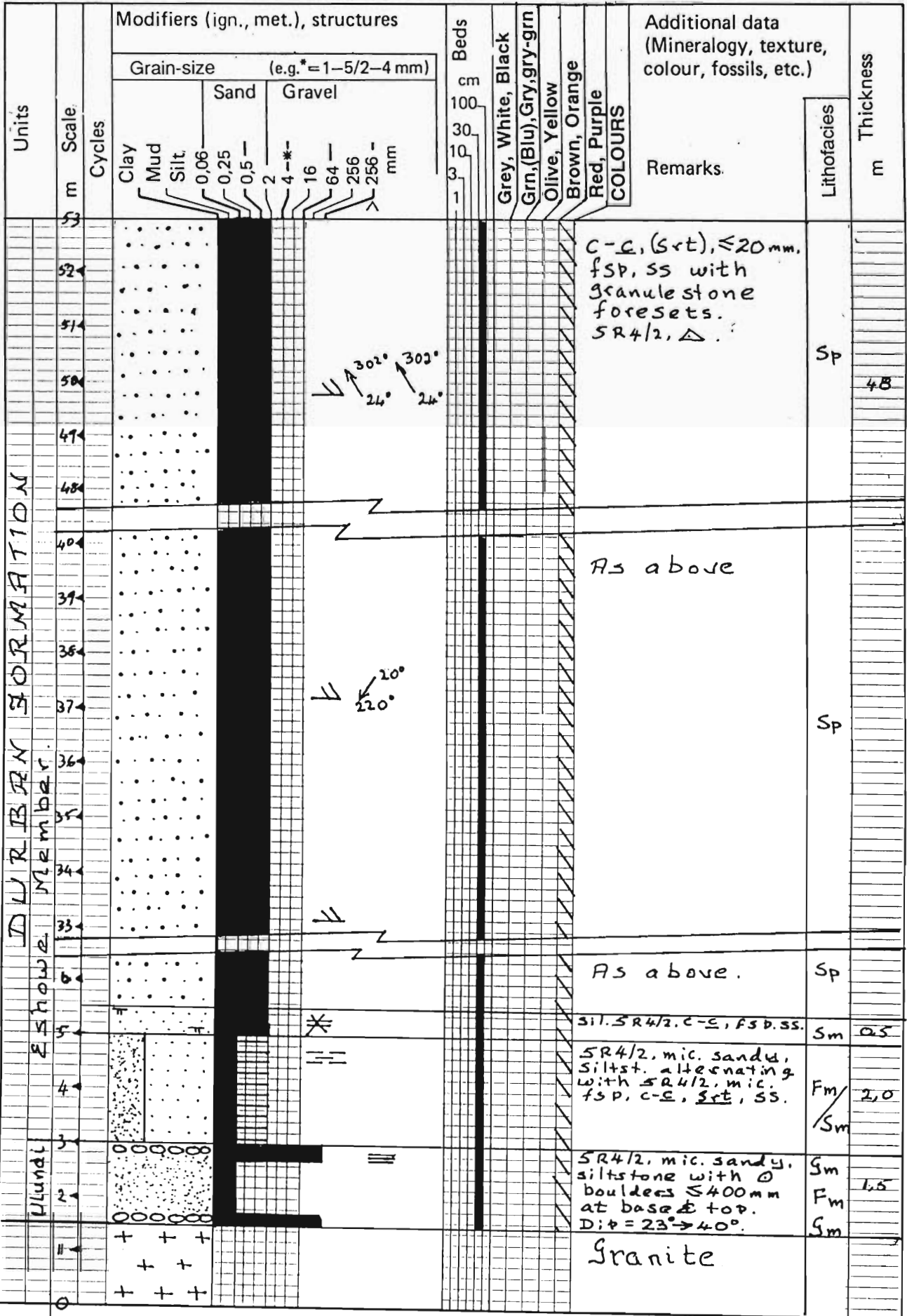


Fig. App-1.11 Measured Section 88 - Nzimbabwe

Units	Scale m	Cycles	Modifiers (ign., met.), structures		Beds cm	COLOURS	Additional data (Mineralogy, texture, colour, fossils, etc.)	Lithofacies	Thickness m	
			Grain-size (e.g. * = 1-5/2-4 mm)							Remarks.
			Clay	Mud						
			0.06 0.25 0.5 2 4 16 64 256 > 256 mm	mm	100 30 10 3 1	Grey, White, Black Grn.(Blu),Gry,gry-grn Olive, Yellow Brown, Orange Red, Purple				
MARIANWILL FORMATION										
	73						As above.			
	72						conglom. as for 60-64 m.	Gms 2.8		
	71						SR4/2, m-c, mic. Srt, fsp. ss. with sparse pebbles ≤20mm with interbedded granulestone.	Sm 3.3		
	70									
	69									
	68						conglom. as for 60-64 m.	Gms 3.7		
	67									
	66									
	65									
	64						Thin beds of small-pebble conglom. and c-c, (Srt), fsp. SR6/2 ss	Sm/Gms 1.0		
	63						Small-pebble, matrix-supp. conglom., ≤300mm, mean=30mm. Clast-supp. in part. Pressure solution hollows common. Matrix is S, SR6/2, SS-granulestone. Clasts: Qtz, Qtz, chert, jasper.	Gms 4.0		
	62									
	61									
	60									
DURBAN Fm.										
	59						SR4/2, c-c, (Srt), (≤20mm Ø), fsp, ss with granulestone foresets.			
	58						mic. shale partings (~10mm) above 58 m.	Sp 6.1		
	57									
	56									
	55									
	54									
	53						SR4/2, mic. siltstone	Fm 0.4		
	52						As below.	Sp		

Notes

UNITS		NATAL GROUP		1: 100	P. 3 of 4					
LOCALITY		Nsizane		HGT	590 m					
LOGGED BY		C.G.A. Marshall		31-08-1988						
Units	Scale m	Modifiers (ign., met.), structures				Beds cm	COLOURS	Additional data (Mineralogy, texture, colour, fossils, etc.)	Lithofacies	Thickness m
		Grain-size (e.g.* = 1-5/2-4 mm)								
	Cycles	Clay	Mud	Silt	Sand	Gravel		Remarks		
		0.06	0.25	0.5	2	4				
					16	64				
					256	256				
					>	>				
					mm					
							Grey, White, Black			
							Grn, (Blu), Gry, gry-grn			
							Olive, Yellow			
							Brown, Orange			
							Red, Purple			
	93							As above.	Sp	
	92							Conglom. matrix fsp. C-C, SR4/2	Gm	0.5
	91							SR4/2, (Srt), fsp. granulestone with interbedded: fsp. C-C (Srt), SR4/2 ss.	Sp	
	90								St	
	89							← Scour filled with granulestone.	Sp	5.5
	88									
	87									
	86									
	85							C-C (Srt), fsp, SS- granulestone, SR4/2 lag conglom. ≤ 30mm.	Sm	0.8
	84							SR4/2, m-c, mic. fsp. ss.	Sm Sp	0.7
	83							C-C (Srt), fsp, SS with granulestone foresets.	Sp	1.5
	82							m, SR4/2, fsp, Srt, mic.	Sp	1.7
	81							C-C (Srt) fsp, SR4/2, SS with granulestone, lag conglom. ≤ 20mm.	Sp	
	80							m-c, SR4/2, fsp, Srt.	Sp Sm Sp	1.3
	79							C-C (Srt), fsp, SR4/2, SS with granulestone foresets.	St Sp	
	78							Sparse pebbles ≤ 65mm.		4.5
	77									
	76								Sp	
	75							SR4/2, mic, silty, m-c, SS, sparse pebbles ≤ 20mm.	St	1.5
	74							SR4/2, C-C, fsp, (Srt), ≤ 30mm. SS.	Sm	
	73							CO ₃ Scouring.	Sm	1.7

MARIKATLIL FORMATION
 Newspaper Member

Notes

UNITS	NATAL GROUP		1: 100	P. 1 of 2
LOCALITY	Ka-Gonitshe		HGT	996 m
LOGGED BY	C.G.A. Marshall		25.5.1989	

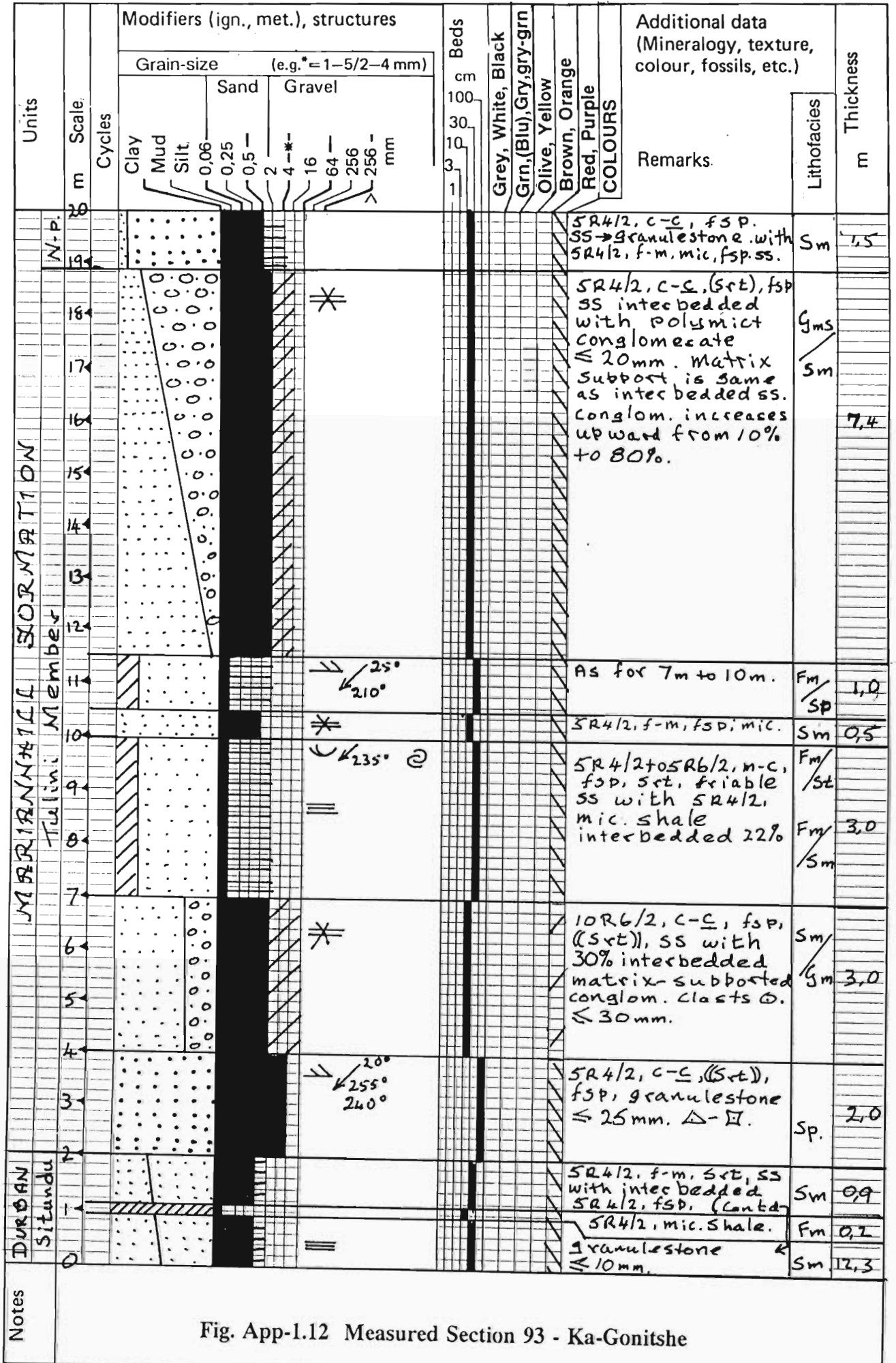
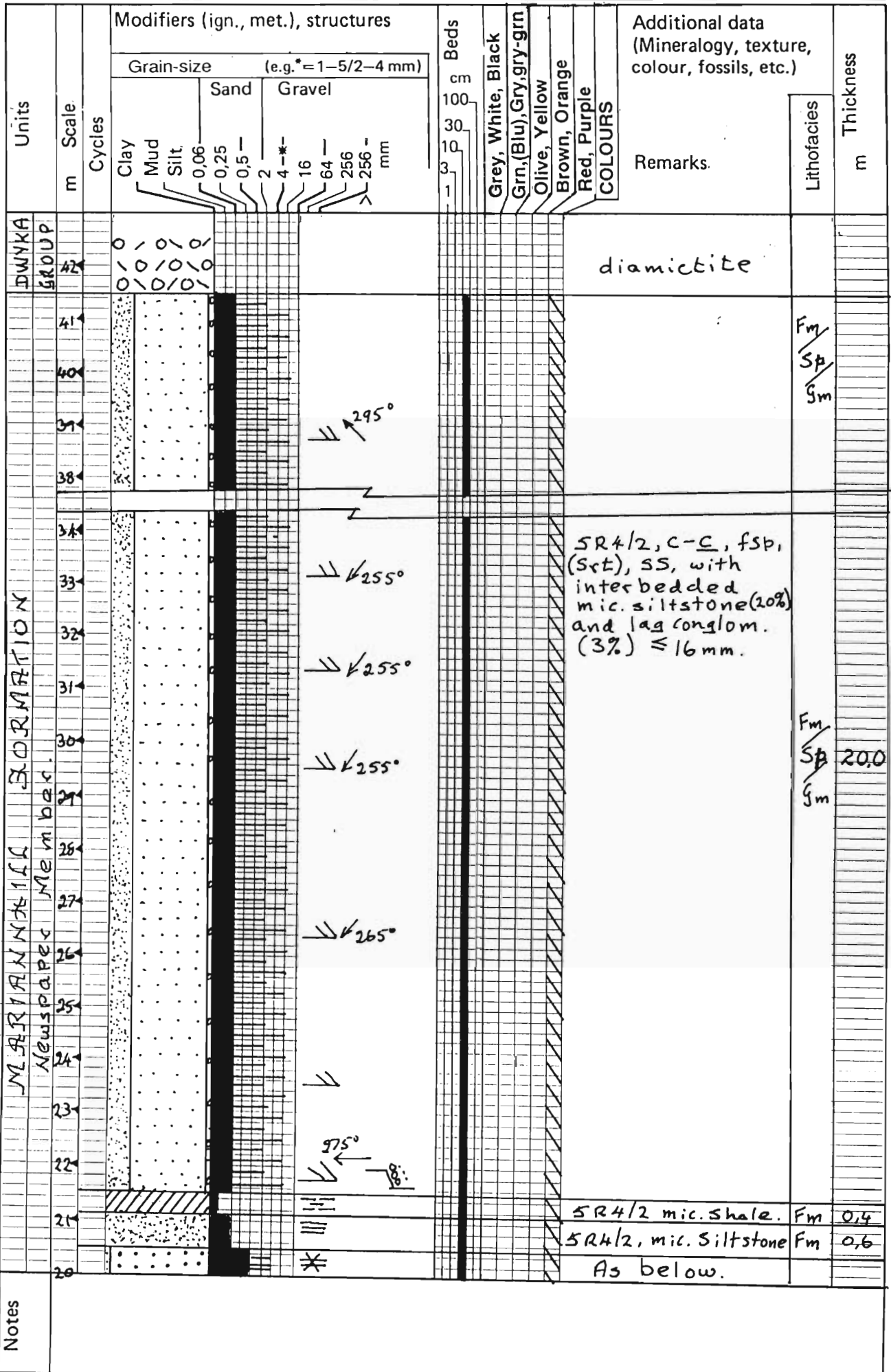


Fig. App-1.12 Measured Section 93 - Ka-Gonitshe

UNITS	NATAL GROUP		1: 100	P.2 of 2
LOCALITY	Ka - Gonitshe.		HGT	996 m
LOGGED BY	C.G.A. Marshall		25-5-1989	



UNITS	NATAL GROUP	1: 100	P. 1 of 2
LOCALITY	Spekfontein	HGT	945 m
LOGGED BY	C.G.A. Marshall	6-6-1989	

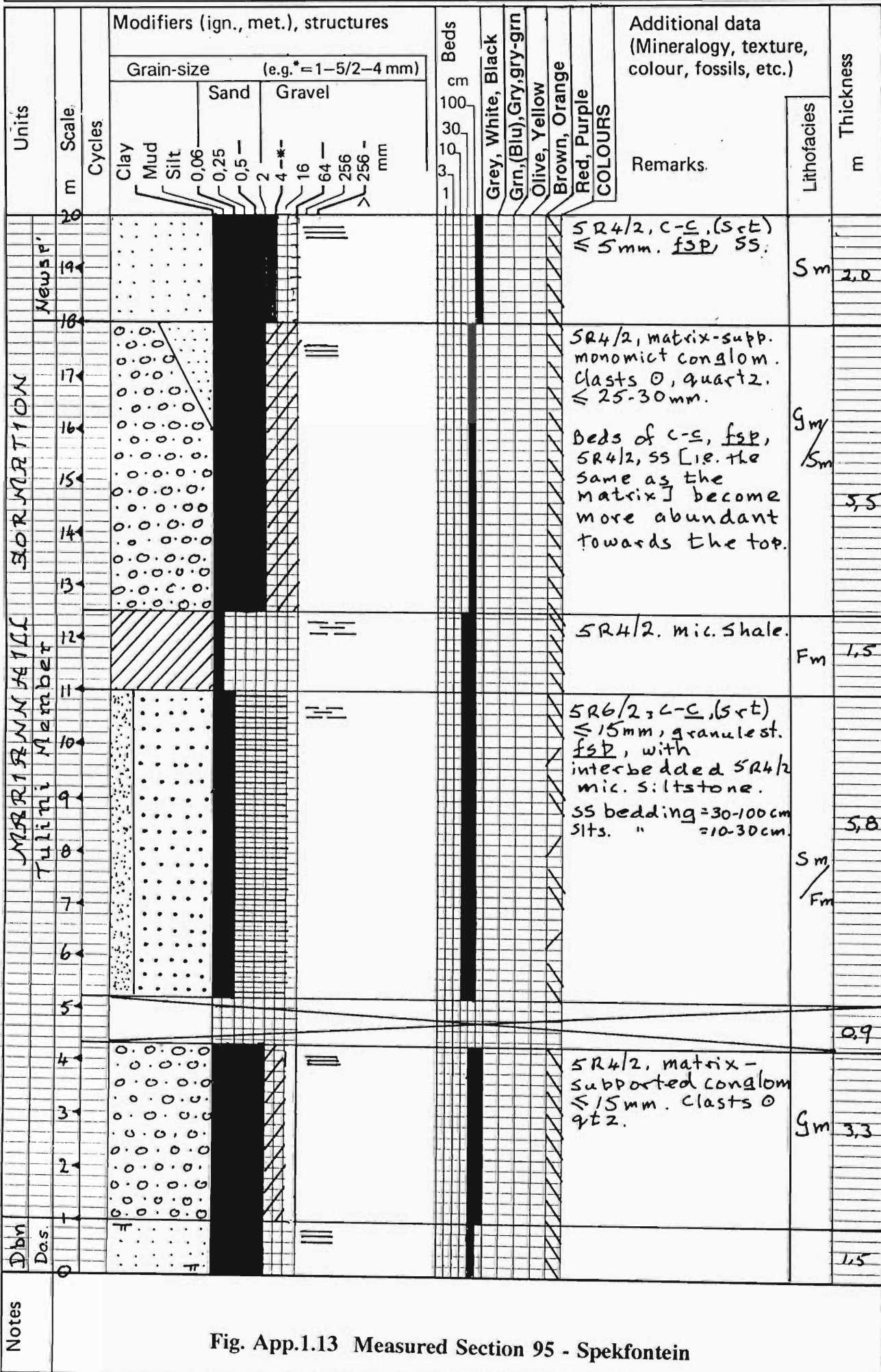


Fig. App.1.13 Measured Section 95 - Spekfontein

UNITS	NATAL GROUP	1: 100	P. 2 of 2
LOCALITY	Spekfontein.	HGT	945 m
LOGGED BY	C.G.A. Marshall	6-6-1989	

Notes	Units	m	Scale	Cycles	Modifiers (ign., met.), structures					Beds cm 100 30 10 3 1	COLOURS Grey, White, Black Grn.(Blu), Gry, gry-grn Olive, Yellow Brown, Orange Red, Purple	Additional data (Mineralogy, texture, colour, fossils, etc.) Remarks.	Lithofacies	Thickness m
					Grain-size (e.g.* = 1-5/2-4 mm)									
					Clay	Mud	Silt	Sand	Gravel					
	MARRINNATHI FORMATION	30												
		29												
		28												
	MARRINNATHI FORMATION	27												
		26												
		25												
	MARRINNATHI FORMATION	24												
		23												
		22												
	MARRINNATHI FORMATION	21												
		20												
		19												
	MARRINNATHI FORMATION	18												
		17												
		16												
	MARRINNATHI FORMATION	15												
		14												
		13												
	MARRINNATHI FORMATION	12												
		11												
		10												
	MARRINNATHI FORMATION	9												
		8												
		7												
	MARRINNATHI FORMATION	6												
		5												
		4												
	MARRINNATHI FORMATION	3												
		2												
		1												
	MARRINNATHI FORMATION	0												
		33												
		34												
	MARRINNATHI FORMATION	35												
		36												
		37												
	MARRINNATHI FORMATION	38												
		39												
		40												
	MARRINNATHI FORMATION	41												
		42												
		43												
	MARRINNATHI FORMATION	44												
		45												
		46												
	MARRINNATHI FORMATION	47												
		48												
		49												
	MARRINNATHI FORMATION	50												
		51												
		52												
	MARRINNATHI FORMATION	53												
		54												
		55												
	MARRINNATHI FORMATION	56												
		57												
		58												
	MARRINNATHI FORMATION	59												
		60												
		61												
	MARRINNATHI FORMATION	62												
		63												
		64												
	MARRINNATHI FORMATION	65												
		66												
		67												
	MARRINNATHI FORMATION	68												
		69												
		70												
	MARRINNATHI FORMATION	71												
		72												
		73												
	MARRINNATHI FORMATION	74												
		75												
		76												
	MARRINNATHI FORMATION	77												
		78												
		79												
	MARRINNATHI FORMATION	80												
		81												
		82												
	MARRINNATHI FORMATION	83												
		84												
		85												
	MARRINNATHI FORMATION	86												
		87												
		88												
	MARRINNATHI FORMATION	89												
		90												
		91												
	MARRINNATHI FORMATION	92												
		93												
		94												
	MARRINNATHI FORMATION	95												
		96												
		97												
	MARRINNATHI FORMATION	98												
		99												
		100												

10 10 10
0 10 10
0 10 10
0 10 10

diamictite

SR4/2, C-C, fsp, SS. Srt → (Srt)

Sp 4.5

20°
180°

SR4/2, C-C, fsp, Srt SS, with sparse lag Conglom. < 15mm. 70% alternating with SR4/2, mic. Shale 30%

Fm / Sp 8.0

20°
250°

Shale beds 5-10cm SS. beds 30-50cm lag Conglom. 5-10cm.

UNITS	NATAL GROUP	1:25	P.1 of 1
LOCALITY	CLANTROCK	HGT	1000 m
LOGGED BY	C.G.A. Marshall	3 - 8 - 1989	

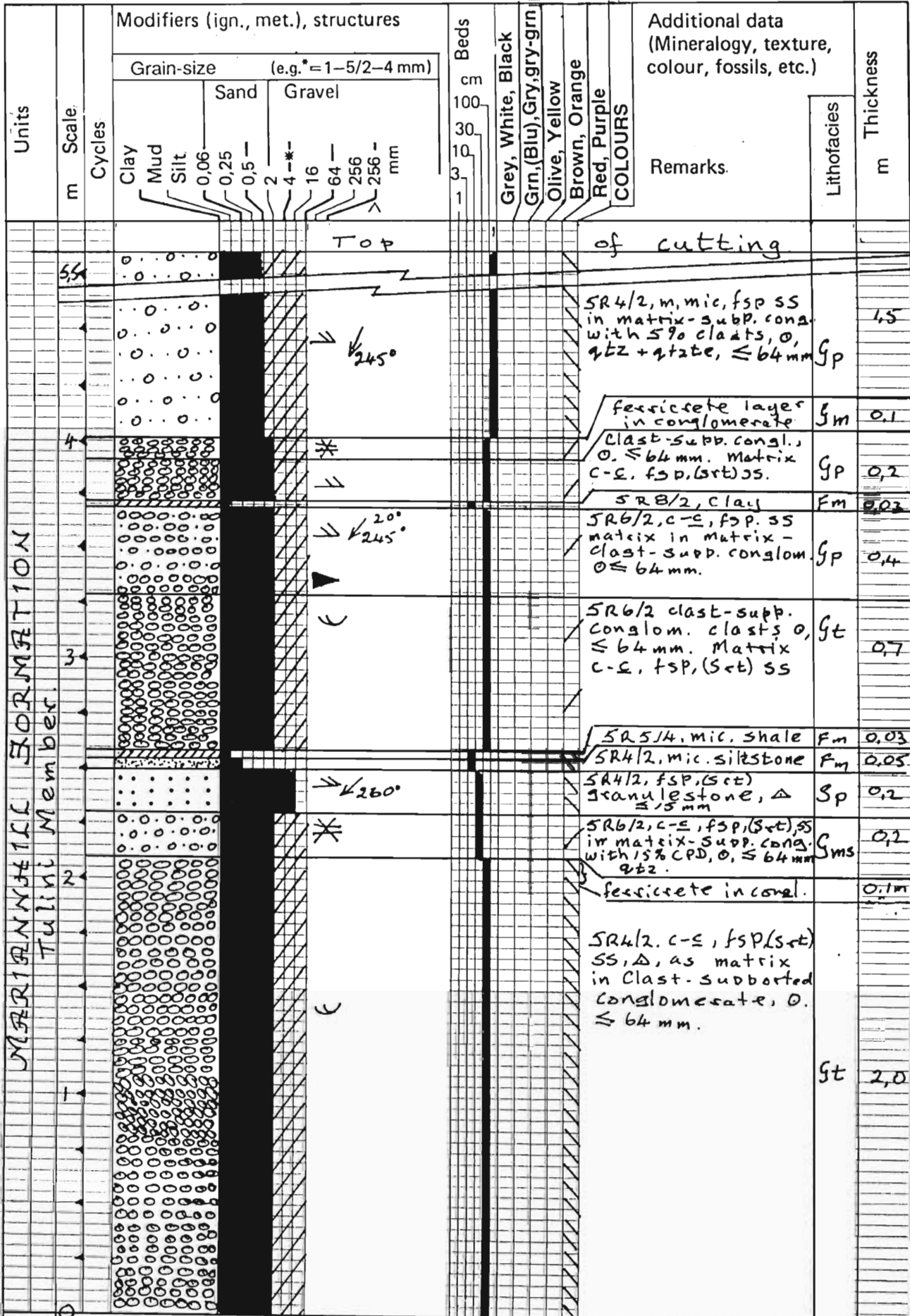


Fig. App-1.15 Measured Section 110 - Clantrock

UNITS	NATAL GROUP		1: 100	P. 1 of 4
LOCALITY	NGCONGANGCONGA		HGT	780 m
LOGGED BY	C.G.A. Marshall		9-9-1989	

Units	m Scale	Cycles	Modifiers (ign., met.), structures		Beds cm	COLOURS	Additional data (Mineralogy, texture, colour, fossils, etc.)	Thickness m		
			Grain-size (e.g.* = 1-5/2-4 mm)						Remarks	Lithofacies
			Clay	Sand						
			Clay Mud Silt 0.06 0.25 0.5 2 4 16 64 256 256 - > mm		100 30 10 3 1	Grey, White, Black Grn.(Blu), Gry, gry-grn Olive, Yellow Brown, Orange Red, Purple				
							Remarks	Lithofacies		
							As above	Sp		
							f-m, silty, SR4/2, srt SS.	Sm	0.5	
							Planar cross-bed sets = 50cm.	Sp		
							21° 227°			
							C-E, SR4/2, fsp.(srt), Δ-◇, SS to granulest. ≤ 10mm.	Sp	8.5	
							Planar cross-bed sets = 25cm.	Sp		
							14° 231°			
							SR4/2, m, fsp, mic. silty SS.	Sp	0.5	
							14 203° 15cm.			
							SR4/2, c-c, fsp, (srt) Δ-◇, SS to granulestone, ≤ 10mm.	Sm		
									4.5	
							SR4/2, m, fsp, srt, SS	Sm	1.0	
							SR4/2, c-c, fsp.(srt), SS to granulestone. Δ-◇, ≤ 8mm	Sp	7.5	
							Planar cross-bed sets 25cm.	Sp		
							13 220°			
								Sp		
							SR4/2, m, fsp, srt, SS.	Sm		
									8.0	
							SR4/2, c-c, (srt), fsp. SS-granulestone, alternating with matrix-supp. conglom. matrix. Granulestone as above. Clasts quartz, CPD = 40% ≤ 35mm \bar{x} = 10mm. Small clasts Δ. Large clasts ○	Sm Sm	9.0	
							Conglom. bed thickness increases upwards from 30cm to 70cm.			

Tullini
 MAFRITHINATHIL
 NEWS PAPER
 MIA MBE
 FORMATION

Fig. App-1.16 Measured Section 115 - Ngcongcongga

UNITS	NATAL GROUP	1: 100	P. 2 of 4
LOCALITY	N5CON5RNSCON5R	HGT	780 m
LOGGED BY	C.G.A. Marshall		9-8-1989

Units	m	Cycles	Modifiers (ign., met.), structures		Beds	COLOURS	Additional data (Mineralogy, texture, colour, fossils, etc.)	Lithofacies	Thickness m							
			Grain-size (e.g.* = 1-5/2-4 mm)							Grey, White, Black Grn.(Blu), Gry, gry-grn Olive, Yellow Brown, Orange Red, Purple	Remarks.	Lithofacies	Thickness m			
			Clay	Mud										Silt	Sand	Gravel
			0.06	0.25												
74							As Above.	Sp								
73																
68							SR4/2, C-G, fsp, (Srt), SS interbedded with 30% SR4/2, mic. siltstone.	Fm Sp	8.5							
67							Planar cross-bed Sets 30cm.									
66							11° 242°									
65							*									
64							SR4/2, mic Siltstone.	Fm	1.5							
63							SR4/2, C-G, fsp (Srt) Δ-◇, granulstone ≤ 12mm.	Sp	5.0							
62							15° 228°									
61							Cross. Planar cross- bed sets 30cm.									
60																
59																
58																
65							SR4/2, C-G, fsp(Srt) SS. Δ-◇.	Sm	16.5							
64							Poor outcrop.									
63																
62																
37							SR4/2, fsp, (Srt) C-G, SS-granulst. Δ-◇. ≤ 12mm	Sp	8.5							
36																
35							14° 224°									
34							Planar Cross-bed Sets = 100cm.									

Notes

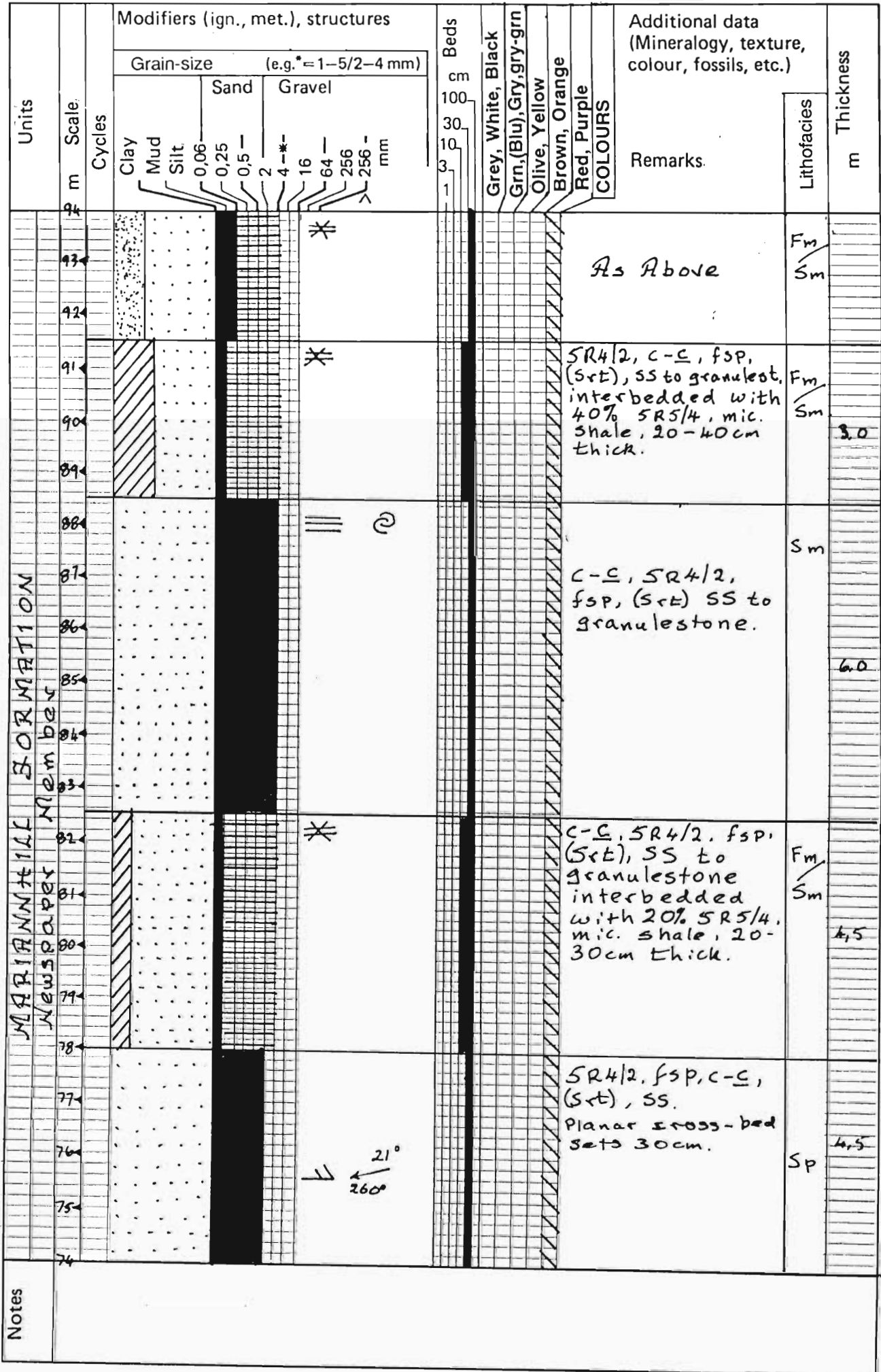
MEMORANDUM

FORMATION

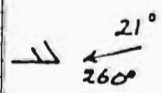
MEMORANDUM

MEMORANDUM

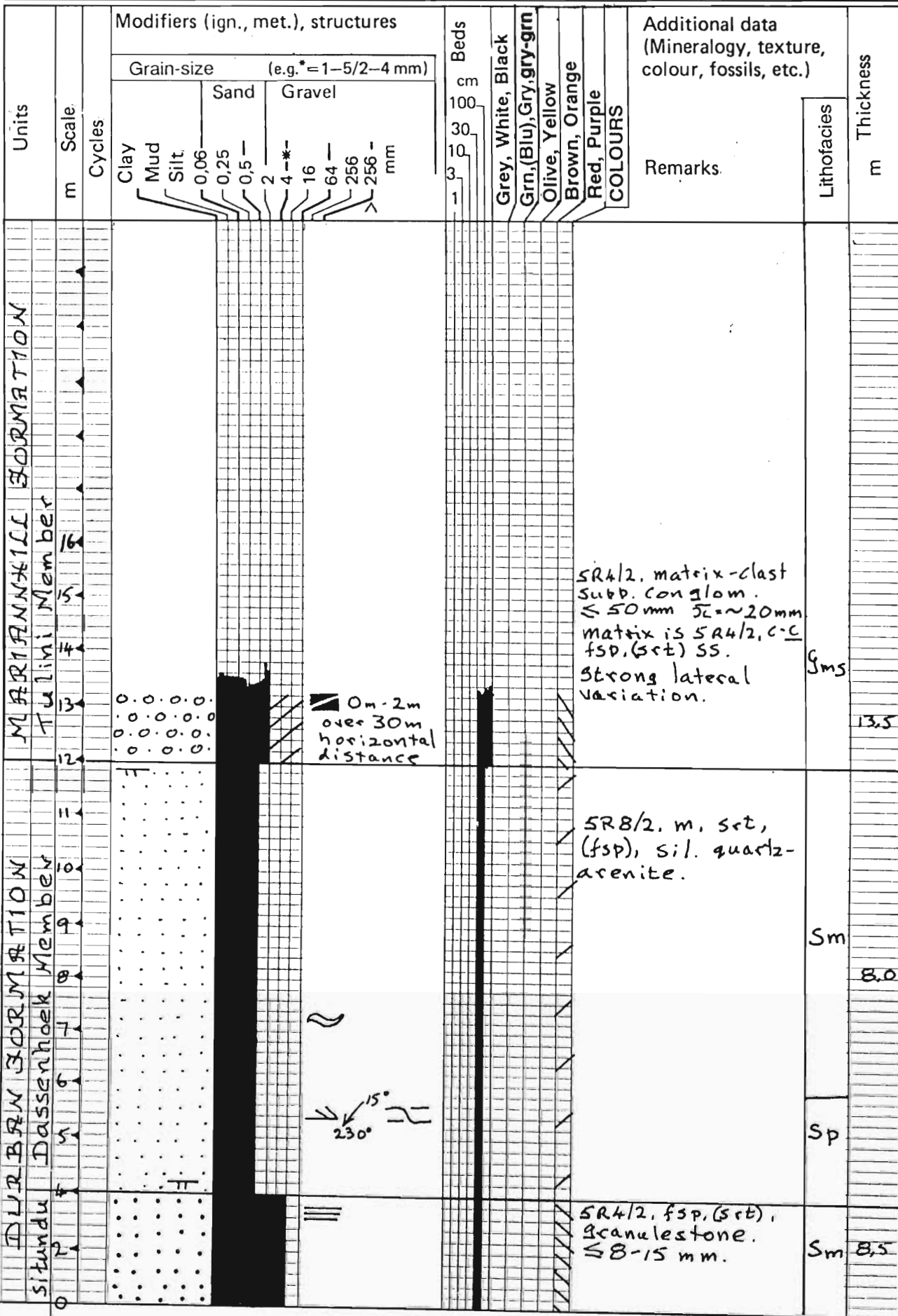
MEMORANDUM



Notes



UNITS	NATAL GROUP	1: 100	P. 1 of 1
LOCALITY	KWAGQUMAGQUMA	HGT	940 m
LOGGED BY	C.G.A. Marshall	31-08 1989.	



Notes

Fig. App-1.18 Measured Section 120 - Kwagqumagquma

UNITS	NATAL GROUP	1: 100	P.1 of 2
LOCALITY	Table Mountain	HGT	945 m
LOGGED BY	C.G.A. Marshall	4-10-1989	

Units	Scale m	Cycles	Modifiers (ign., met.), structures		Beds cm	COLOURS	Additional data (Mineralogy, texture, colour, fossils, etc.)	Lithofacies	Thickness m	
			Grain-size (e.g. * = 1-5/2-4 mm)							
			Clay	Sand						Gravel
DURBAN FORMATION transcribed members	20									
	19			*			SR6/2, srt, (fsp), m, quartz-arenite.			
	18								0.7	
	17			*					2.0	
	16									
	15			*				Sm	0.3	
	14			∨				Sp	0.7	
	13							Sm	1.5	
	12								4.5	
	11			∨ ↗ 60°						
	10									
	9									
	8							SR4/2, m-c, srt, fsp, ss alternating with SR7/2, (fsp) srt, m quartz-arenite. 50%-50%		
	7								Sm	7.0
	6			faint						
5										
4										
3			*							
2										
1										
Escombe							c-e, fsp (srt), SR6/2 ss with 10% interbedded SR6/2 mic. shale. sparse pebbles ≤ 15 mm.	st	2.0	
Notes	Fig. App-1.19 Measured Section 125 - Table Mountain									

Fig. App-1.19 Measured Section 125 - Table Mountain

UNITS	NATAL GROUP		1: 100	P. 2 of 2
LOCALITY	Table Mountain		HGT	94.5 m
LOGGED BY	C.G.A. Marshall		4-10-1989	

Units	m Scale	Modifiers (ign., met.), structures					Beds	COLOURS	Additional data (Mineralogy, texture, colour, fossils, etc.)	Lithofacies	Thickness m										
		Clay	Mud	Grain-size (e.g.* = 1-5/2-4 mm)		Gravel															
				Sand	Gravel																
	Cycles	0.06	0.25	0.5	2	4	16	64	256	> 256	mm										
DURBAN FORMATION Kranskop Member	47																				
	46																				
	45																				
	44																				
	43																				
	42																				
	41																				
	40																				
	39																				
	38																				
37																					
36																					
35																					
34																					
33																					
32																					
31																					
30																					
Notes																					

DURBAN GROUP

DURBAN FORMATION
Kranskop Member

0/0/0/0
0/0/0/0
0/0/0/0
0/0/0/0

≡ faint

*

*

*

47
46
45
44
43
42
41
40
39
38
37
36
35
34
33
32
31
30

≡ faint

*

*

*

Gms

Sm 9.5

0.5

Sm 15.3

diamictite and
varved shale

SR6/2, Sst, (fsp),
m, quartz-arenite

Remarks

Lithofacies

Thickness
m

Grey, White, Black

Grn, (Blu), Gry, gry-grn

Olive, Yellow

Brown, Orange

Red, Purple

COLOURS

Additional data
(Mineralogy, texture,
colour, fossils, etc.)

Remarks

Lithofacies

Thickness
m

Grey, White, Black

Grn, (Blu), Gry, gry-grn

Olive, Yellow

Brown, Orange

Red, Purple

COLOURS

Additional data
(Mineralogy, texture,
colour, fossils, etc.)

Remarks

Lithofacies

Thickness
m

Grey, White, Black

Grn, (Blu), Gry, gry-grn

Olive, Yellow

Brown, Orange

Red, Purple

COLOURS

Additional data
(Mineralogy, texture,
colour, fossils, etc.)

Remarks

Lithofacies

Thickness
m

Grey, White, Black

Grn, (Blu), Gry, gry-grn

Olive, Yellow

Brown, Orange

Red, Purple

COLOURS

Additional data
(Mineralogy, texture,
colour, fossils, etc.)

Remarks

Lithofacies

Thickness
m

Grey, White, Black

Grn, (Blu), Gry, gry-grn

Olive, Yellow

Brown, Orange

Red, Purple

COLOURS

Additional data
(Mineralogy, texture,
colour, fossils, etc.)

Remarks

Lithofacies

Thickness
m

Grey, White, Black

Grn, (Blu), Gry, gry-grn

Olive, Yellow

Brown, Orange

Red, Purple

COLOURS

Additional data
(Mineralogy, texture,
colour, fossils, etc.)

Remarks

Lithofacies

Thickness
m

Grey, White, Black

Grn, (Blu), Gry, gry-grn

Olive, Yellow

Brown, Orange

Red, Purple

COLOURS

Additional data
(Mineralogy, texture,
colour, fossils, etc.)

Remarks

Lithofacies

Thickness
m

Grey, White, Black

Grn, (Blu), Gry, gry-grn

Olive, Yellow

Brown, Orange

Red, Purple

COLOURS

Additional data
(Mineralogy, texture,
colour, fossils, etc.)

Remarks

Lithofacies

Thickness
m

Grey, White, Black

Grn, (Blu), Gry, gry-grn

Olive, Yellow

Brown, Orange

Red, Purple

COLOURS

Additional data
(Mineralogy, texture,
colour, fossils, etc.)

Remarks

Lithofacies

Thickness
m

Grey, White, Black

Grn, (Blu), Gry, gry-grn

Olive, Yellow

Brown, Orange

Red, Purple

COLOURS

Additional data
(Mineralogy, texture,
colour, fossils, etc.)

Remarks

Lithofacies

Thickness
m

Grey, White, Black

Grn, (Blu), Gry, gry-grn

Olive, Yellow

Brown, Orange

Red, Purple

COLOURS

Additional data
(Mineralogy, texture,
colour, fossils, etc.)

Remarks

Lithofacies

Thickness
m

Grey, White, Black

Grn, (Blu), Gry, gry-grn

Olive, Yellow

Brown, Orange

Red, Purple

COLOURS

Additional data
(Mineralogy, texture,
colour, fossils, etc.)

Remarks

Lithofacies

Thickness
m

Grey, White, Black

Grn, (Blu), Gry, gry-grn

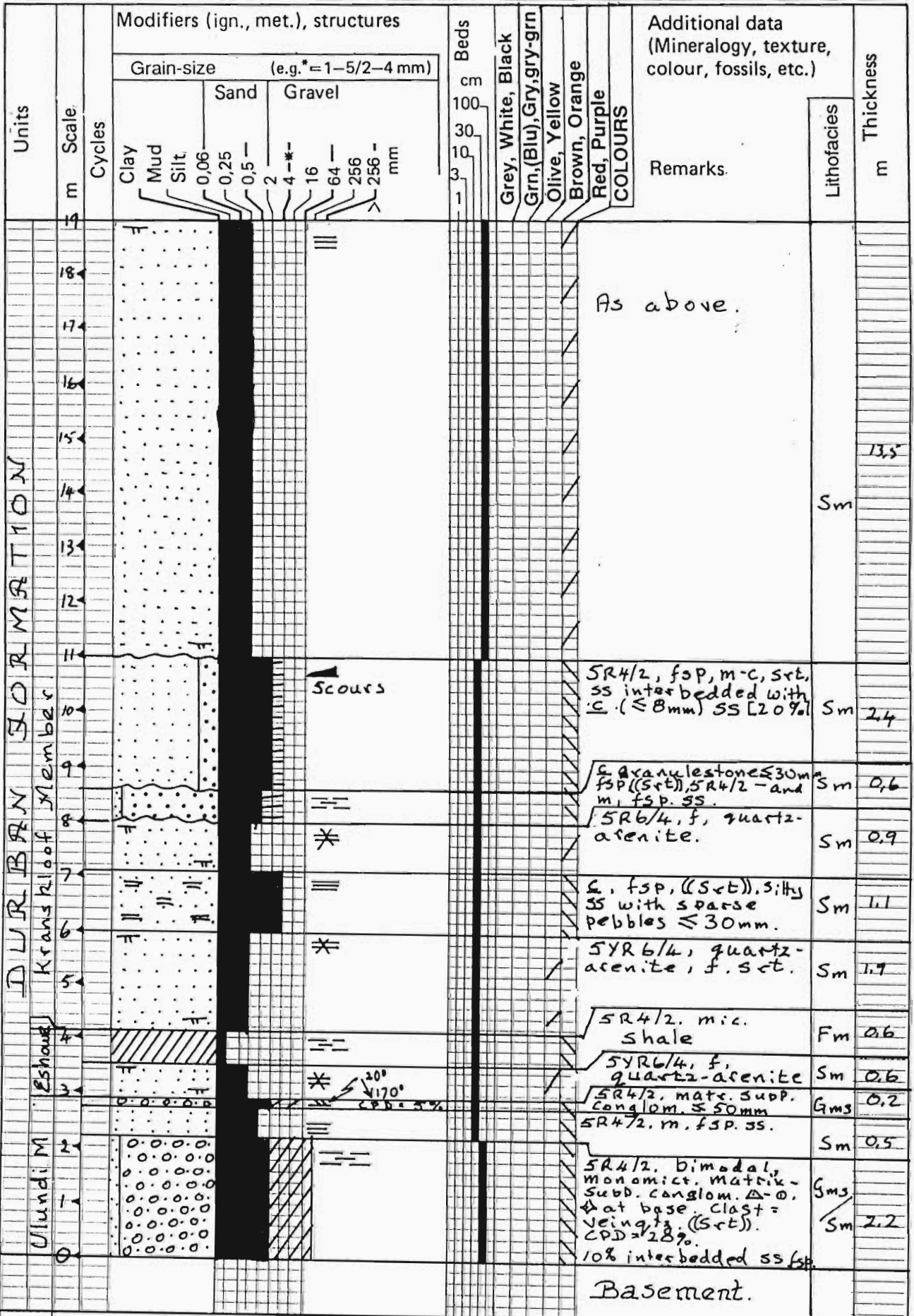
UNITS	NATAL GROUP	1: 100	P.1 of 1
LOCALITY	Nkwazi	HGT	640 m
LOGGED BY	C.G.A. Marshall	2B-B-1990	



Fig. App-1.21 Measured Section 136 - Nkwazi

Notes

UNITS	NATAL GROUP	1: 100	P. 1 of 2
LOCALITY	Ntabakucasha	HGT	686 m
LOGGED BY	C.G.A. Marshall	5-9-1990	



Notes: The break at ~25m corresponds to a similar break in section 136 (Inkwazi). Deposits in this area are lenticular, as there is high palaeorelief. The Kranskloof lenses from 32m in thickness to 0m over a mere 200m horizontal distance.

UNITS	NATAL GROUP	1: 100	P. 2 of 2
LOCALITY	Ntabakucasha	HGT	686 m
LOGGED BY	C.G.A. Marshall	5-9-1990	

Units	m	Cycles	Modifiers (ign., met.), structures		Beds cm	Grey, White, Black Grn.(Blu), Gry, gry-grn Olive, Yellow Brown, Orange Red, Purple COLOURS	Additional data (Mineralogy, texture, colour, fossils, etc.)	Lithofacies	Thickness m										
			Grain-size (e.g.*=1-5/2-4 mm)							Remarks.									
			Clay	Sand							Gravel								
			Clay	0.06	0.25	0.5	2	4	16	64	256	> 256	mm						
DURBAN FORMATION Kranskloof Member	38																		
	37																		
	36																		
	35			0 \ 0 / 0 - 0															
	34																		
	33			000000000000															
	32																		
	31																		
	30																		
	29																		
28																			
27																			
26																			
25																			
24																			
23																			
22																			
21																			
20																			
19																			
Notes	These is a thin lens of Dassenhoek quartz-arenite just north of this locality.																		

245° ↘

15° ↘
170° ↘

CPD = 6%

diamictite

single-layer lag
conglom. ≤ 100 mm.

SR6/4, f, quartz-arenite.

SR4/2, m, fsp,
friable, matrix
supported conglom.
Clasts = qtz, ≤ 12cm.

SR6/4, f, quartz-arenite.

Gms

Sm

Gms

8.5

Sm

Sp

Gms

1.5

Sm

13.5

UNITS	NATAL GROUP		1: 100	P. 1 of 1
LOCALITY	190XR		HGT	945 m
LOGGED BY	C.G.A. Marshall		11-10-1990	

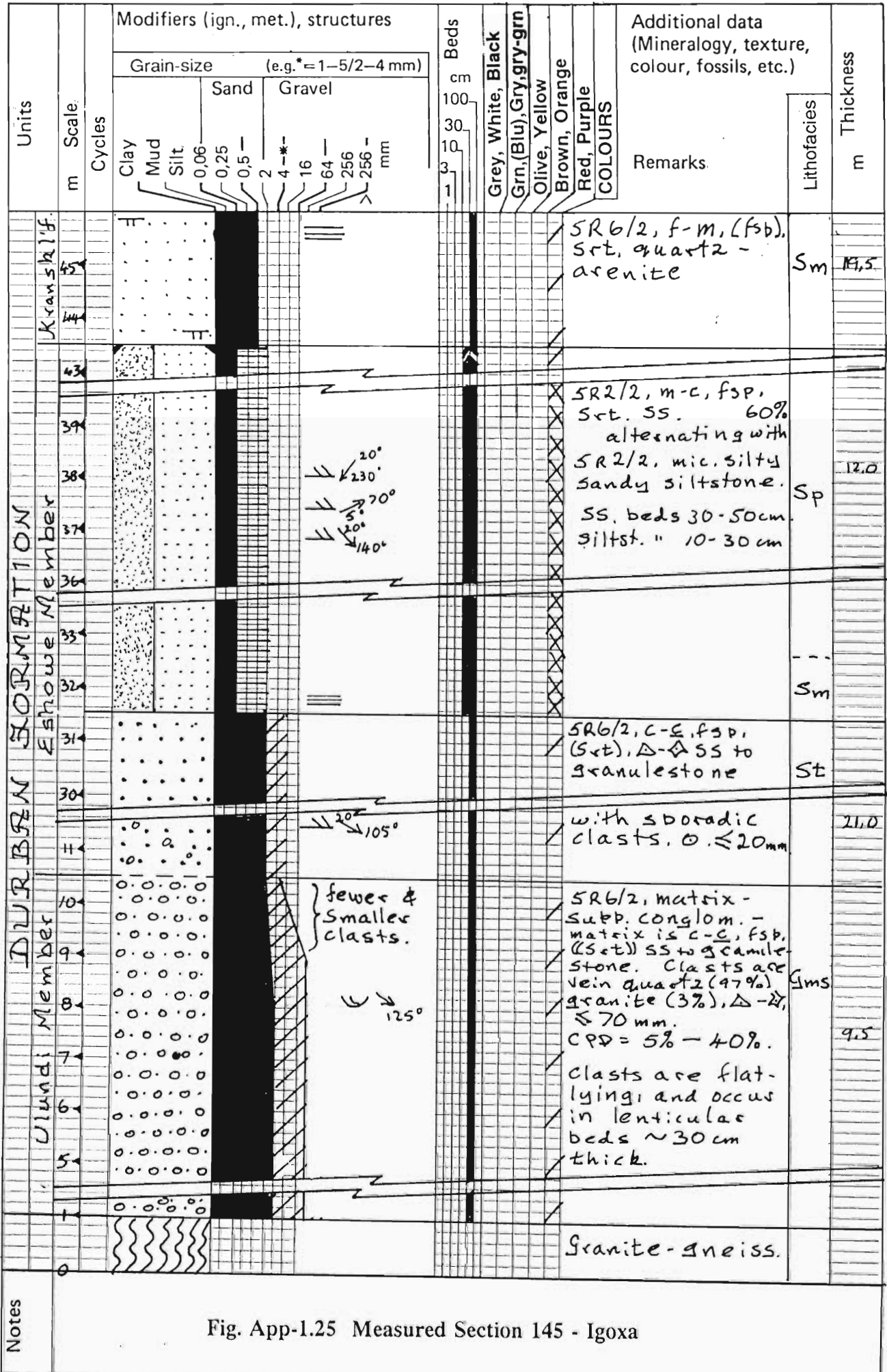


Fig. App-1.25 Measured Section 145 - Igoxa

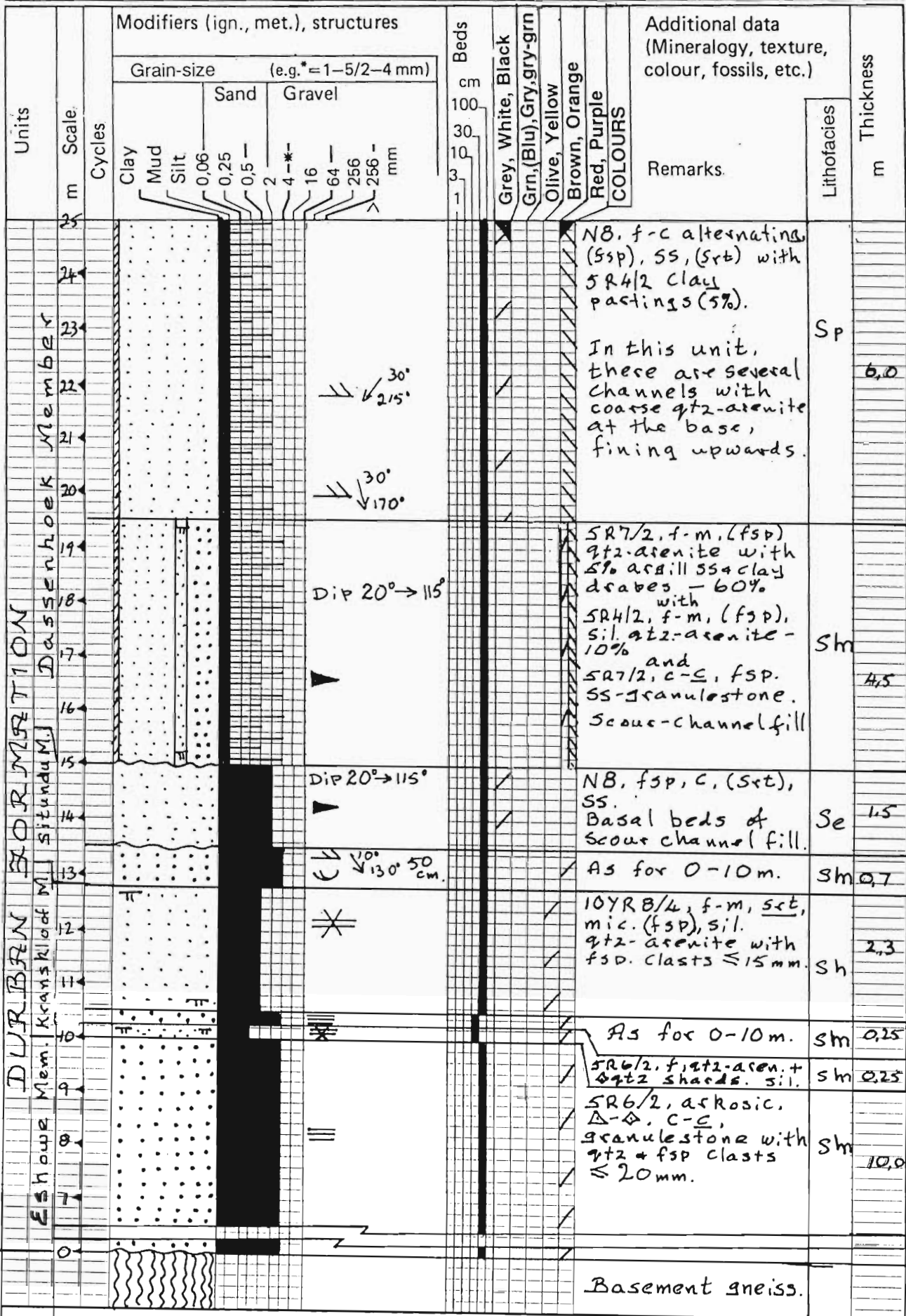


Fig. App-1.26 Measured Section 146 - Gibraltar

Notes

SECTION	Ulundi	Eshowe	K'K'l'f	Situndu	D'h'k	Tul.	N'pap	W'vill	Msik.	No.
Assegaai Toll					13.0					6
Nhlangwini				72.0						51
Vuma Reform	0.5	37.5								67
Tevreden II								5.7		72
Ndlovana	8.0									75
White Mfolozi	64.4									76+78
Tevreden IV								6.6		77
Kwa Seme								32.2		86
Nzimane	1.5	58.5				12.8	26.4			88
Ka-Gonitshe						16.9	22.6			93
Spekfontein						17.0	14.5			95
Hlimbitwa				5.0		27.0				99
Clantrock						5.6				110
Ngcongangeonga						9.0	95.0			115
Sherbrook						16.0				119
Kwagcumagecuma					8.0					120
Table Mountain			42.0							125
Mgwahumbe								15.0		132
Nkwazi		1.0								136
Ntabakucasha	2.9	1.4	30.4							137
Hlutankungu						28.0				138
Mtwalume			28.5							139
Igoxa	9.5	33.0	19.5							145
Gibraltar		10.0	0.25	4.75	10.5		33.0		16.5	146
Mtwalume Nat.Reserve									305.0	151

- K'K'l'f = Kranskloof Member
 D'h'k = Dassenhoek member
 Tul = Tulini Member
 N'pap = Newspaper Member
 W'vill = Westville Member
 Msik = Msikaba Formation
 No. = Consecutive numbering of measured sections

Figures in the member columns indicate thicknesses reported in metres.

Table App-1.2 Measured stratigraphic sections included in dissertation, indicating thicknesses reported.

Table App-1.3

Lithofacies and sedimentary structures, modified after Miall (1977)

Facies Code	Lithofacies	Sedimentary Structure	Interpretation
Gms	massive, matrix-supported gravel	none	debris flow deposits
Gm	massive or crudely-bedded gravel	horizontal bedding, imbrication	longitudinal bars, lag deposits, sieve deposits
Gt	gravel, stratified	trough cross-beds	minor channel fills
Gp	gravel, stratified	planar cross-beds	linguoid bars or deltaic growths from older bar remnants
St	sand, medium to v. coarse, may be pebbly	solitary (theta) or grouped (pi)trough cross-beds	dunes (lower flow regime)
Sp	sand, medium to v. coarse, may be pebbly	solitary (alpha) or grouped (omicron) planar cross-beds	linguoid, transverse bars, sand waves (lower flow regime)
Sr	sand, very fine to coarse	ripple marks of all types	ripples (lower flow regime)
Sh	sand, very fine to very coarse	horizontal lamination, parting or streaming lamination	planar bed flow (l. and u. flow regime)
Sm	sand, medium to v. coarse, may be pebbly	massive or horizontal lamination	planar bed flow (upper flow regime)
Se	erosional scours with intraclasts	crude cross bedding	scour fills
Ss	sand, fine to coarse	broad, shallow scours including efa cross-bedding	scour fills
Sse,She, Spe	sand	analogous to Ss,Sh,Sp	aeolian deposits
Fl	silt, mud	fine lamination, very small ripples	overbank or waning flood deposits
Fsc	silt, mud	laminated to massive	backswamp deposits
Fcf	mud	massive, with freshwater molluscs	backswamp pond deposits
Fm	mud, silt	massive, dessication cracks	overbank or drape deposits
Fr	silt, mud	rootlets	seatearth
C	coal, carbonaceous mud	plants, mud films	swamp deposits
P	carbonate	pedogenic features	soil

APPENDIX 2. GEOLOGICAL MAPS

Locality map (Fig. App-2.1) shows the areas covered by the 1:50 000 geological maps (Figs. App-2.2 to App-2.14) included in a pocket at the back of this dissertation.

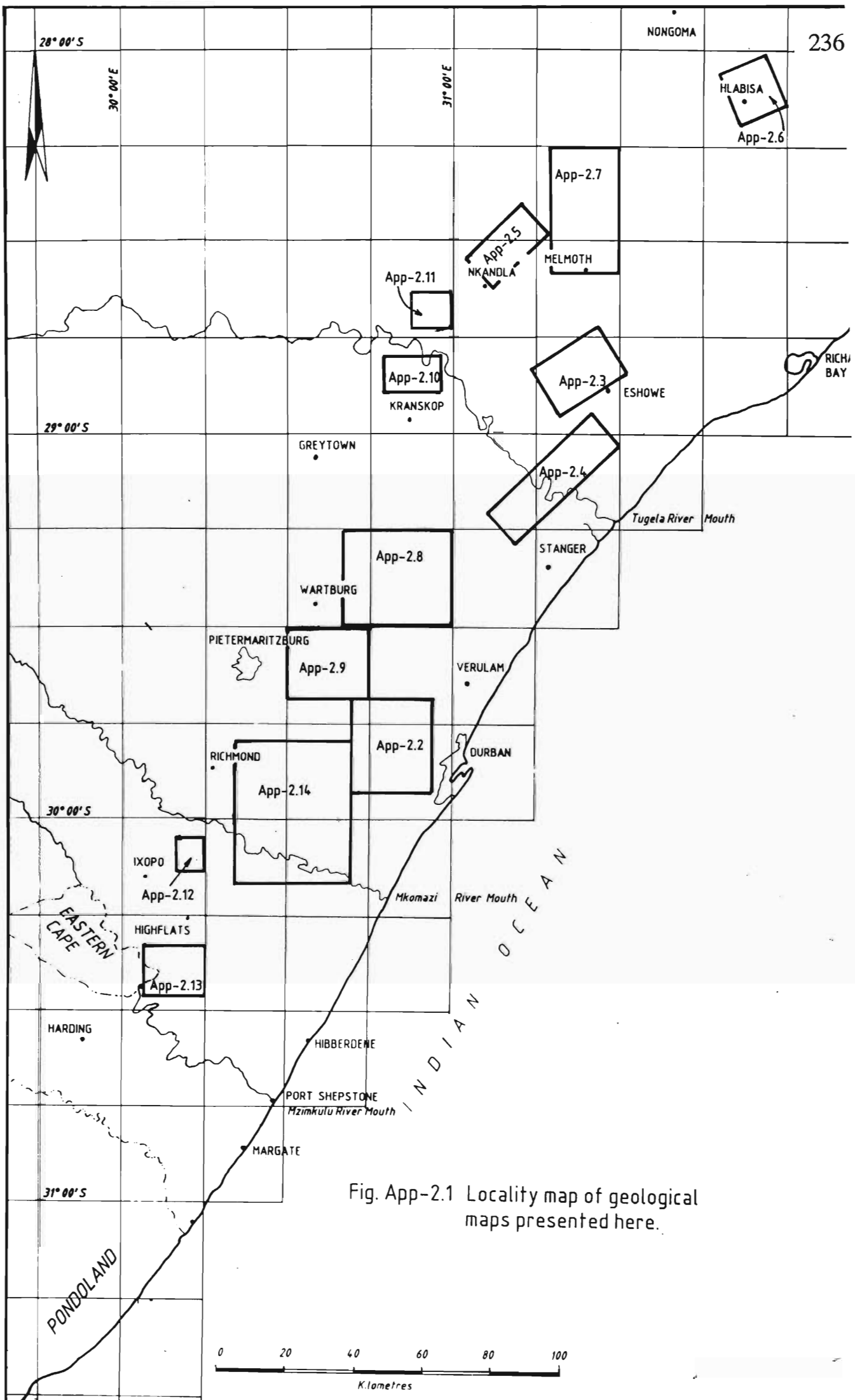


Fig. App-2.1 Locality map of geological maps presented here.

APPENDIX 3. GRAIN-SIZE ANALYSIS AND COMPOSITION

The determination of the composition of the mineral grains, and their longest visible diameter, are laborious and time-consuming tasks, but are necessary for the understanding of the sedimentary rocks which the samples represent. Assembling the data, and the scientific analysis thereof, provided some insight into the provenance rocks and the conditions under which the particles were transported and deposited, as well as the post-depositional history.

A total of 600 samples of Natal Group rocks was collected. These were taken from selected localities over the entire known basin of deposition, and represent every unit within the Natal Group. Because of the indurated nature of the Natal Group rocks, the samples could not be disaggregated for sieving and accurate determination of grain-size distribution, and grain-size measurements were thus carried out under the microscope.

APP-3.1 COMPOSITION

The modal compositions of the rocks were determined using, initially, a Swift Model C Point Counter, with a mechanical stage mounted on a Leitz Ortholux II Pol-BK microscope. The following minerals were identified: monocrystalline quartz (including coarsely-crystalline composite grains); polycrystalline quartz (including chert and jasper); feldspar (including potash and plagioclase feldspar); clay (usually now sericite, but interpreted as detrital clay); sericite (usually as wisps along grain boundaries); zircon; garnet; amphibole; detrital iron oxide; detrital calcite; detrital muscovite; detrital biotite; and cement (usually quartz, but also sparse calcite).

The distance chosen between the count points is less critical for composition than for grain-size measurements. If two, or more, observation points fall within one grain, this does not affect the modal composition. However, if the interval chosen is too large, many of the smaller grains - such as zircon, which commonly occurs as very small grains in sedimentary rocks - might be missed, and a compositional bias introduced, regardless of how many observations are made. When the measuring point fell on cement or some other non-detrital material, only the composition was recorded. The size of a further grain was measured during an extended survey to ensure that a minimum of 400 grains per sample was measured for maximum diameter.

Holmes (1930) stated that, in determining mineral composition using the linear method, the length of the measured line must be at least 100 times the average diameter of the constituents measured. Relating this to the point-counting method employed by the author, it is clear that 400 grain counts would exceed this minimum requirement by a factor of approximately four. It was determined, using the chart of van der Plas and Tobi (1965), that it was unnecessary to count more than 400 grains per thin-section, as set out in the Table App-3.1. Johnson (1994) opined that 50 to 100 grains would be sufficient.

Table App-3.1 Accuracy of point counts (from van der Plas and Tobi, 1965)

Hypothetical Case	Count	Confidence Level	Mineral Content	Accuracy Limit	Increased Count	Increased Accuracy
A	400	95%	90%	3%		
	900	95%	90%	2%	500	1%
B	400	95%	60%	5%		
	600	95%	60%	4%	200	1%

The number of grains for each mineral was converted to volume percentage of the whole

sample. As the point-counting method determines, directly, only the areal percentages of the various minerals present, it is necessary to relate this to the volume percentage. It was assumed that the Delesse relation applies (Chayes, 1956), and that the areal percentage of a mineral in the thin-sections measured is a direct indication of its volume percent in the rock (Holmes, 1930). However, as it is necessary to represent the mineral composition of the rocks as mass percentage, the relative densities of each mineral were used to do this further calculation (Holmes 1930). The formula used was:

$$\text{Mass percent of mineral in sample} = \frac{\text{Number of grains} \times \text{Relative density} \times 100}{\Sigma(\text{Number of grains} \times \text{relative density})}$$

The compositions of the various samples and the units they represent, are discussed under the relevant headings in Chapter 3. The compositions are listed in Table App-3.2.

APP-3.2 GRAIN-SIZE

The mineral grains were measured using a graduated eyepiece on the Leitz Ortholux microscope. Care was taken to ensure that no grain diameter was measured twice, as this would introduce a bias towards the larger grain-sizes, although it would not have introduced any bias as far as mineral composition is concerned. Where two or more consecutive measuring points did indeed occur within one grain, the composition of the grain was recorded for each step, but the diameter was recorded for only the first measuring point. After 400 positions were recorded, the survey was extended to record diameters only, until a total of 400 diameters was also recorded for that thin section.

Where there was obvious overgrowth, usually discernible from the dust line of haematite showing the original grain boundary, the original grain diameter was measured. In a closely

SAMPLE	MEAN DIAM PHI	STD. DEVN	SKEW	KURT	n	Qtz	Fsp	Chrt	Jasp	Clay	Ser	Biot	Cemt	Zirc	Garn	Amph	FeO	Calc	Musc	LITHIC	Other	Total	STRAT.
491	1.61	1.49	0.35	2.57	536	64	28.5	2.2		3.3	1.8		0.2									100	KR
492	1.55	0.51	1.2	7.75	373	96.5		2.2			1.2											100	KR
493	1.24	0.85	-0.1	2.27	426	85.6	5.3	8.7			0.5											100	KR
494	2.02	0.83	1.24	3.99	481	83.1	7.62	6			3.2											100	ES
496	1.74	0.88	0.37	2.87	591	92.8		4.8			2.4											100	KR
498	2.2	1	1.56	7.98	400	59.3	33.4	2.2			4.1						0.98					100	NP
500	3.58	1.09	0.34	4.31	403	34	1.76	4.23		37.2	14.2		0.2				8.39					100	NP
501	2.48	1.63	1.74	6.04	402	50.8	25.8	6.1		12.1	1.35						3.87					100	ES
502	2.18	1.84	2	6.21	464	82	2.37	2.2		8.63	2.43						2.42					100	ES
503	2.04	1.14	2.94	13.7	412	89.5	0.48	5.15		1.63	0.81						2.43					100	ES
504	2.27	1.6	1.93	6.7	400	77.9	0.23	4.99		4.46	3.94						8.48					100	ES
505	2.53	0.69	2.91	21.9	416	84.5		7.04		2.42	2.68						3.37					100	ES
506	2.02	1.82	1.72	5.88	407	72.7	10.7	3.35		8.2	0.79						4.27					100	ES
507	1.84	0.94	2.69	14.8	414	89.3	0.24	2.2		2.16	2.7						3.4					100	ES
508	1.71	0.82	3.08	21.4	405	91.5		2.39		1.06	1.32						3.79					100	ES
509	1.79	0.9	3.2	18.4	401	84.5	6.94	4.94		1.37	0.82						1.47					100	ES
510	1.58	0.76	2	13.4	405	91.8		2.22		0.5	2.99						2.44					100	ES
511	1.99	0.72	1.15	4.62	403	80.1	0.45	5.57			0.51						13.4					100	ES
512	1.93	0.75	1.28	5.28	402	93.7		3.24		1.93	1.1											100	KR
513	1.93	0.8	2.57	14.7	402	90.7	0.24	4.71		3.84							0.49					100	KR
513b	1.22	0.77	0.85	5.44	402																	0	KR
514	1.95	0.99	2.13	11.7	417	80.4		3.8		4.72	2.1						8.95					100	ES
515	2.47	1.2	1.43	7.74	440	84.4		6.36		5.47	0.52						3.27					100	ES
516	1.65	0.7	1.74	14.5	418	93.5		5.44		0.27	0.82											100	KR
517	1.67	0.56	2.92	29.7	417	91.6		7.08		1.35												100	KR
518	1.91	0.85	2.42	15.5	413	93.1		4.46		2.46												100	KR
520	1.86	0.92	1.34	9.37	408	74.3		7.51		0.73	0.24			2.34			14.9					100	KR
521	1.53	0.72	2.11	16	410	92.8		5.78		0.27	0.27			0.43			0.48					100	KR
523	2.28	1.09	2.06	9.87	409	87.2	4.34	0.75		6.04	1.65											100	ES
526	5.77	2.11	-0.5	1.43	408	34		0.48		63.5	2.12											100	ES
527	2.15	1	2.78	14.9	402	85		3.54		2.35	2.09						7.03					100	ES
530	1.18	0.89	0.32	2.56	408	72.5	0.48	4.7		0.82			20				1.47					100	ES
533	3.5	1.02	2.07	9.06	403	74.4	2.22	2.06		6.07	1.27			0.81			13.2					100	ES
534	1.98	1.87	0.72	4.36	404																	0	ES
661	2	2.2	1.18	3.89	410	58.6	21.7			1.07	0.81		17	0.86								100	ES
669	3.14	2.13	0.75	3.02	406	54.8	10.5	2.54		9.72	4.6		9.25				7.81	0.71				100	NP
672	2.51	1.07	0.7	2.64	398																	0	NP

MZ = MZIKABA
WE = WESTVILLE
NP = NEWSPAPER
TU = TULINI
DA = DASSENHOEK
SI = SITUNDU
KR = KRANSKLOOF
ES = ESHOWE
UL = ULUNDI

Std Devn = Standard deviation
Skewn = Skewness
Kurt = Kurtosis
n = Grains measured

The figures under the columns below
are calculated percentages

Qtz = Quartz
Fsp = Feldspar
Chrt = Chert
Jsp = Jasper
Clay = Clay
Ser = Sericite
Biot = Biotite
Cemt = Quartz cement
Zirc = Zircon
Garn = Garnet
Amph = Amphibole
FeO = Iron oxide, mainly cement
Calc = Calcite, mainly cement
Musc = Muscovite
Lithic = Lithic components
Other = Other unidentifiable
Total = Total percentage calculated

Table App-3.2 Grain-size and composition statistics
Sheet 1 of 3

SAMPLE	MEAN DIAM PHI	STD. DEVN	SKEW	KURT	n	Otz	Fsp	Chrt	Jasp	Clay	Ser	Biot	Cemt	Zirc	Garn	Amph	FeO	Calc	Musc	ITHIC	Other	Total	STRAT.
680	1.33	1.18	0.84	2.54	397	63.1	20.5	4.17			6.79		0.49	0.43	0		2.92	0.25	1.36			100	NP
693	1.86	0.69	0.53	4.06	400	86.7		4.75	0.25				7.49			0.3			0.55			100	KR
705	2.53	0.81	0.7	5.96	400	74.8	2.38	9.35	0.49		0.27		8.12	1.3			1.95		1.36			100	KR
711	1.35	0.8	1.2	5.77	400	77.5	11.1	2.48			7.69		0.5				0.49		0.27			100	SI
712	1.02	1.08	0.78	3.28	400	77.1	12.1	2.5		0.55	4.14		2.75						0.83			100	SI
715	2.48	0.52	0.55	4.09	401	80	1.66			0.54	11.1		2.94	0.43			1.46		1.89			100	SI
717	1.62	0.63	1.21	6.2	400	85.6	2.61	1.22		0	1.62	0	4.16	1.3			2.91		0.54			100	DA
718	0.85	0.43	0.64	5.45	400	90.8	2.4	3.46					0.99	0.44			1.96					100	DA
720	-0.3	0.9	0.7	3.57	400	72.4	12	6.31					8.83				0.5					100	DA
725	2.69	0.58	0.5	3.53	400	82		5.87	0.98		4.06		2.45	0.86	0.59		2.43		0.81			100	KR
728	0.85	0.8	0.82	4.02	400	62.5	16.8	5.61			0.28		14.3				0.51					100	KR
736	1.81	0.58	0.55	3.44	400	85.7		6	1		0.28		7									100	KR
753	1.51	0.73	0.93	3.71	400	85		5	1.2		0.28		8.5									100	KR
781	0.85	0.8	0.82	4.02	400	61.4	16.5	5.51			0.28		14				0.5			1.82		100	NP
788	2.23	0.79	0.6	2.82	400	58.6	5.27	4.01		15.4	0.26		0.71	0.42	0		7.5	6.54	1.31			100	NP
792	2.02	0.72	0	2.98	400	79.3	3.64	0.75			0.28		16									100	DA
806	1.6	0.93	0.92	3.37	400	89.2		6.93	0.25		0.82		0.99	0.87			0.98					100	KR
810	1.56	1.08	-0.5	3.65	400	75	11.3	0.99		1.1	8.49		1.24				0.49		1.37			100	SI
811	0.9	0.97	1.25	4.87	400	62.5	11.9	0.97		0	14.9		4.34	0	0		4.79	0	0.53			100	SI
813	1.81	0.44	0.85	5.09	400	87	0.48	3.25			0.28		9									100	DA
818	1.68	0.69	0.4	2.71	400	83.9		6.2	1.74				7	0.88	0.3							100	KR
818	1.16	0.72	0.91	4.23	400	76.7		5.2					16.1				1.97					100	KR
819	1.42	0.54	0.51	5.54	400	87	0.24	1.25					11.5									100	KR
821	1.5	0.55	-0.0	3.85	400	87.8		1.25					11									100	KR
827	1.13	0.45	1.03	6.67	400	79.8		2.24			0.28		17.2				0.49					100	ES
832	1.89	0.64	0.75	3.76	400	82.2		3.48			1.92		10.9	0.44			0.49		0.55			100	ES
835A	2.3	0.66	1.72	12.5	400	82.3		4.43	0.25		1.91		8.38		0.3		2.45					100	ES
835B	2.29	0.6	0.92	4.48	400	81.7		5.93	0.74	0.55	3.55		4.94	0.44	0.89		0.98		0.27			100	ES
845	2.29	0.6	0.92	4.48	400	79.3	3.33	2.45	0.25		11.9		0.25	0.43	0.3		0.97		0.81			100	ES
849	0.88	0.94	0.7	4.49	394	84.8	6.79	2			2.21		4.25									100	ES
853	2.41	0.61	0.32	3.62	200	98	0.48	1											0.55			100	DA
855	1.58	0.99	0.24	3.48	400	66.5	17.6	2.26			7.21		1	0.44			2.49	1.54	0.83			100	NP
857					400	72.6	12.6	0.72			2.67		3.62	0.85			6.7		0.27			100	ES
870	0.97	1.17	0.37	2.73	400	72.7	12.5	6.45			6.04		0.75				0.99		0.55			100	ES
875	2.88	0.83	0.62	4.79	400	73.9	3.99	0.48			18.5			1.28			1.92					100	KR
877	2.08	0.59	0.57	4.3	400	86.1		6.82	0.25		3.07		3.28				0.5					100	ES
881	2	0.52	1.38	6.78	400	89.6		4.99			1.93		3.49									100	KR
882	1.93	0.4	0.69	5.17	400	87		5.75	0.25		0.28		6.75									100	KR
894					801	78.3	9.6	4.83			5.75						1.23		0.27			100	ES
896	2.07	0.75	0.29	3.44	400	80.1	6.72	0.5	0.25		10.1		1.98					0.25				100	ES
908					407	65.3	31.9	0.49						0.44					1.91			100	UL
909	0.72	0.99	-0.1	2.58	400	59.8	35.8	1.26	1.01		0.28		0.5				1		0.28			100	UL

SAMPLE	MEAN DIAM PHI	STD. DEVN	SKEW	KURT	n	Qtz	Fsp	Chrt	Jasp	Clay	Ser	Biot	Cemt	Zirc	Garn	Amph	FeO	Calc	Musc	lITHIC	Other	Total	STRAT.
911	2.11	0.57	0.68	4.08	400	75.9	18.5	3.02			0.56		2.01									100	ES
942	0.03	1.22	0.66	4.24	180	82.5	13.3	2.19	0.55	0.61	0.61											100	ES
950	0.99	0.9	-0.3	4.03	401	82.8	8.47	3.99	0	0	4.41								0.28			100	SI
951	1.76	0.74	1.13	4.85	398	91.6		1.24			5.47		0.74				0.98					100	SI
959	1.85	0.46	0.75	4.88	400	82.4		6.49	1		1.1		8.99									100	KR
961	1.92	0.39	0.45	3.39	400	92.7		2			0.28		4.75			0.3						100	KR
966	2	0.52	0.72	5.15	400	80.1	2.64	3.47	0.5		3.84		8.43				0.98					100	ES
971	2.38	0.51	0.62	4.06	400	82.4	4.8	3		0.28	2.21		6.99			0.3						100	ES
977	1.64	0.72	-0.5	3.68	400	77.1	13.6	1.51					7.78									100	KR
982	1.91	1.23	-0.4	2.67	201	86.9	8.72	0	0.5		1.1		2		0.74							100	KR
988	1.72	0.82	0.93	3.29	400	64.9	21.8	4.04			4.19								5.03			100	NP
989	0.86	1.11	0.34	2.63	398	75.5	13.7	2.23			4.92		1.24	0.44			1.47		0.55			100	KR
990	1.74	0.78	-0.5	4.06	400	82.2	3.61	3.72	0.25		5.77		3.97				0.49					100	KR
992	1.99	0.6	1.14	5.14	400	86.8	0.96	2.24	0.25		5.77		3.98									100	DA
993	1.75	0.66	0.55	3.18	400	87.8		4.7			4.65		1.48	0.87			0.49					100	DA
995	1.51	0.8	0.16	4.62	394	73.1	16.3	1.98			0.55		0.99				2.94	3.04	1.09			100	NP
996	1.74	0.81	-0.2	4.05	400	81.8		4.69			12.6		0.99									100	SI
1004	1.92	0.52	0.67	4.47	400	76.3	9.36	3.22			9.31		0.25				0.49		1.1			100	NP
1005a	1.74	0.53	0.00	4.43	400	88.1		0.75					10.7	0.44								100	MZ
1005	1.29	0.7	0.72	5.19	400	97.4		1.24						1.32								100	MZ
1016	1.94	0.55	0.31	3.37	400	76.9	8.9	2.74			1.65		8.46	0.88			0.49					100	ES
1024	1.17	1.43	-0.1	2.44	403	63.1	19.5	3.23			13.5		0.25				0.49					100	ES
1027	2.26	0.69	0.71	3.95	400	80.5	10.1	1.49	0.25		6.3			0.44			0.98					100	KR
1028	2.05	0.53	0.76	4.8	400	83.8	1.93	6.48			0.55		6.73				0.49					100	DA
1030	2.24	0.61	0.88	3.84	400	54.6	19.2	5.96			6.59							3.82	0.55		9.18	100	NP
1041	2.12	0.62	1.14	4.62	400	83.2	1.66	2.97			7.67		3.96				0.49					100	NP
1043	1.79	0.65	0.38	4.83	400	92.6		3			1.38		3									100	MZ
1044	1.24	0.93	0.53	2.9	400	71.2	13.8	1.5	0.25		1.11		12									100	ES

Table App-3.2 Grain-size and composition statistics
Sheet 3 of 3

packed sediment, such as is the case with virtually all the Natal Group rocks, overgrowth would not significantly change the diameter of the grains, and therefore the author did not consider this a matter of major concern, especially as the number of samples in which original grain boundaries were not discernible, was minimal. As the Natal Group is essentially unmetamorphosed, there has been no recrystallization, and hence no increase in grain-size apart from that caused by overgrowth during silicification (cementation by quartz).

Inaccuracies can occur when this method is adopted, as any diameter measured in thin-section can be either equal to or, as is usually the case, less than the original diameter of the grain, but never greater. Orientation of the grain relative to the plane of the thin-section, and the position of the plane of the thin-section within the original grain, both play significant roles in determining how close the measured maximum thin-section diameter approaches the maximum diameter of the original grain. Computations using the data derived in this way must, of necessity, have a bias towards results which would indicate that the rock has a finer grain-size than is actually the case. This problem was addressed by Friedman (1958) who has prepared a chart (his Fig.4) whereby microscope measurements can be related to sieve sizes for sediment grains. There is some doubt as to the validity of Friedman's conversion. His formula is as follows: $\phi_{\text{sieve}} = (\phi_{1/s} \times 0.90909) + 0.3636$. In this regard, the constant addition of 0,3636 would have a different effect depending on the grain-size, as ϕ is logarithmic (Reddering, pers. comm.¹), but no better conversion factor could be found. Johnson (1994) has further refined the conversion of grain-sized measured in thin-section to sieve-sizes. He proposed obtaining the true nominal diameter - to within 5% or $0,07\phi$ (phi) - by multiplying the long axes (in mm) observed in thin-section by 0,95, or by adding 0,05 to the

¹ J.S.V. Reddering, Council for Geoscience, Port Elizabeth

corresponding ϕ values. However, as nominal diameters were not used in the interpretation of results, this technique was not employed in the current investigation.

The observed largest diameter of each grain was converted to sieve size dimensions on the ϕ scale, using the method of Friedman (1958). The grain measurements were then grouped in $1/2\phi$ classes (Folk 1966) and treated statistically on a Quattro Pro 4 spreadsheet, using standard statistical parameters.

Dunlevy and Mitchell (1993), involved the present author in developing a point-counting computer programme which enabled the mechanical stage of the point-counter to be coupled to a computer, and activated by the computer keyboard. Using this facility, up to 30 different mineral species or variants can be accommodated, and up to three other parameters such as maximum grain length, recorded. Each grain composition and maximum grain diameter, in micrometer eyepiece graduation marks were fed into the computer. The software automatically converted the graduations into millimetres, using a factor supplied by the operator and depending upon calibration of the objective lens in use, and kept a running tally of the number of each mineral type recorded. The raw data file was then imported into Quattro-Pro 4 (a spread sheet programme), parsed and sorted according to grain-size. The grain diameters were converted into phi units, and, using Friedman's (1958) data, converted from thin-section sizes, into sieve sizes. The grains were grouped into $1/2 \phi$ classes, and the totals of these classes fed into a spreadsheet where the four moments were calculated (See below). This technique obviated much monotonous and time-consuming hand recording and conversion of data. The formula used to convert millimetres to Phi-units is:

$\phi = -\text{Log}_2\text{Size in mm}$ (Dunlevy and Mitchell, pers. comm. ²)

APP-3.3 STATISTICAL PARAMETERS

Grain-size is a fundamental descriptive element of a sedimentary rock, and should therefore be measured and analysed with reasonable precision (Roberts, 1981). It is also useful in interpreting source rocks, transport and depositional processes and environments. The intention was to be able, with reasonable confidence, to corroborate the hypothesis - formulated on the grounds of palaeocurrent consistency, and on pebble shape parameters - that the Natal Group rocks were deposited in fluvial rather than marine conditions. Of the two main approaches available, the moments method (Friedman, 1961), which utilises the whole of the distribution to analyze the weight frequency distribution data derived from granulometric analysis (Folk, 1966; Mc Manus, 1992), was favoured. There is the proviso that the moments method requires complete fine and coarse tails (Reddering, pers. comm.³), but it was considered preferable to the graphic method in the light of the finite number of grains measured under the microscope. The graphic approach uses only five quartile points on the cumulative grain-size distribution curve plotted on probability paper (Blatt *et al.* 1972), and is therefore not as representative. The moments method is ideal for microscopic determinations because of the discrete number of grains measured. Folk (1966) expressed some degree of doubt as to the validity of the moments method, whereas Friedman (1961, 1962), Folk and Ward (1957) and Swan *et al.* (1979) have favoured this method. Swan *et al.* (1978) suggested that the difference between the graphic and calculated ungrouped

² J.N. Dunlevy and A.D. Mitchell, Dept. of Geology, University of Durban Westville

³ J.S.V. Reddering, Council for Geoscience, Port Elizabeth

moment means are so small that, in most cases, they can be ignored. It is clear that the parameters derived by the graphic method differ slightly from those derived by the method of moments (Folk 1966, Friedman 1962 and Middleton 1967). However, Folk (1966) considered that this is not a serious problem, and stressed that the same geologic conclusions would be reached no matter which method is used, because sample-to-sample variation in most geologic suites is so large that it would outweigh precise hair-splitting over details of statistical orthodoxy.

Many authors in the field (e.g. Krumbein and Pettijohn 1938, Inman 1952, Folk and Ward 1957, Mason and Folk 1958, Folk 1959, 1966, Friedman 1961, 1962, Swan *et al.* 1978, 1979, McLaren 1981, Friedman and Johnson 1982, and Pettijohn *et al.* 1987) have utilized the mean diameter, sorting, skewness and kurtosis to aid in the understanding of the provenance, transport and deposition of the sediments concerned. The author has determined the same parameters. The maximum grain-size, although considered useful in interpreting transport and deposition conditions, was not determined. This property, measured in thin-section, might bear no relation at all to the maximum grain-size of the rock, especially if the rock is poorly sorted, as is usually the case with the Natal Group sedimentary rocks. Friedman's (1958) conversion does not apply to maximum grain-size conversions, as the number of grains is too small, and the possibility of measuring the actual maximum diameter extremely remote.

McLaren (1981) emphasized that, in the absence of supporting data, grain-size analyses of sediments from unknown sources, cannot enable the interpreter to be very specific as to environment of deposition. No definite, widely-applicable correlation between grain-size distribution and the depositional environment has yet been formulated (Mc Manus, 1992).

The author has adopted the following moments, as defined by Friedman and Johnson (1982). The symbols used are: x_ϕ = mean diameter (ϕ); m_ϕ = midpoint of size class (ϕ); f = mass percentage of grain-size class in sample; Σ = the sum; δ = standard deviation; $\beta_{3\phi}$ = third moment, or skewness; $\beta_{4\phi}$ = fourth moment, or kurtosis.

APP-3.3.1 FIRST MOMENT Mean Size (x_ϕ) = $\Sigma f m_\phi / 100$

This is the arithmetic mean of the largest observed diameters of the grains measured (Friedman and Johnson, 1982), and reflects the overall average size of the sediment as influenced by the source of supply and the environment of deposition (Folk, 1966).

APP-3.3.1.1 Mean Grain Size

Mean grain-size classes used below are according to Pettijohn *et al.* (1987). The data are listed in Table App-3.2 and summarised in Tables App-3.3 and App-3.4.

APP-3.3.2 SECOND MOMENT

This is a measure of the dispersion of particle sizes about the mean, and is actually the standard deviation, and thereby defines the degree of sorting of the sample. It is process-sensitive, and therefore useful in distinguishing different source environments (Friedman and Johnson, 1982).

$$\delta = (\Sigma f (m_\phi - x_\phi)^2 / 100)^{1/2}$$

APP-3.3.2.1 Sorting

The verbal classification is according to both Folk and Ward (1957) and Friedman (1962) unless otherwise stated. The results are summarised in Tables App-3.3; App-3.4

Table App-3.3: Grain-size distribution statistics

UNIT	n	1st Moment (Mean Diameter, ϕ)			2nd Moment (Sorting)			3rd Moment (Skewness)			4th Moment (Kurtosis)		
		Maximum	Minimum	Mean	Maximum	Minimum	Mean	Maximum	Minimum	Mean	Maximum	Minimum	Mean
Ulundi	1	0.72	0.72	0.72	0.99	0.99	0.99	-0.10	-0.10	-0.10	2.58	2.58	2.58
Eshowe	37	0.03	5.7	2.01	0.45	2.20	1.03	-0.50	3.20	1.34	1.43	21.9	7.45
Kranskloof	33	0.85	2.88	1.74	0.39	1.49	0.74	-0.54	2.92	0.83	2.27	29.7	6.44
Situndu	8	0.90	2.48	1.47	0.52	1.08	0.86	-0.50	1.25	0.49	3.28	5.77	4.32
Dassenhoek	9	-0.30	2.41	1.57	0.43	0.90	0.61	0.00	1.21	0.69	2.98	6.20	4.45
Newspaper	13	0.85	3.58	2.07	0.52	2.13	0.96	0.16	1.56	0.74	2.54	7.98	3.97

Table App-3.4 Verbal Grain-size and Sorting of the Natal Group

UNIT	MEAN GRAIN-SIZE <i>Pettijohn et al. (1987)</i>	MEAN SORTING (VERBAL) <i>Folk and Ward (1957)</i>	MEAN SORTING (VERBAL) <i>Friedman (1962)</i>
<u>Newspaper Member</u>	Fine-grained sandstone	Moderately sorted	Moderately sorted
<u>Dassenhoek Member</u>	Medium-grained sandstone	Moderately sorted	Moderately sorted
<u>Situndu Member</u>	Medium-grained sandstone	Moderately sorted	Moderately sorted
<u>Kranskloof Member</u>	Medium-grained sandstone	Moderately sorted	Moderately-to-well sorted
<u>Eshowe Member</u>	Fine- to medium-grained sandstone	Poorly sorted	Moderately sorted
<u>Ulundi Member</u>	Coarse-grained sandstone	Moderately sorted	Moderately sorted

APP-3.3.3 THIRD MOMENT

This moment, known as skewness, is a measure of the symmetry of the distribution frequency about the mean (Friedman and Johnson, 1982), or can be expressed as the non-normality of the distribution (Folk, 1966).

$$\beta_{3\phi} = (\sum f (m_{\phi} - x_{\phi})^3) / (100 \times \delta^3)$$

There is some confusion regarding the interpretation of skewness, and few workers use this parameter. Grain-size characteristics owe their origin to their source rather than to the depositional environment (McLaren, 1981). Therefore, he further pointed out, a negative or a positive skew is not diagnostic, but a positive or negative trend in the change of the skewness relative to its source identifies the sedimentary process. Skewness values are strongly affected by the presence or absence of coarse and fine fractions in a population. Positively skewed samples have mean grain-size values which are finer than the median, while negatively-skewed samples have mean grain-size values which are coarser than the median (Friedman, 1961).

APP-3.3.3.1 Skewness The results are summarised in Table App-3.3.

The verbal classification is after Folk and Ward (1957) who classified between the limits of -1,0 and +1,0. Friedman (1962) allowed a much wider range. Where the calculated values fall outside the range of Folk and Ward (1957) the author has added the qualifier "extremely".

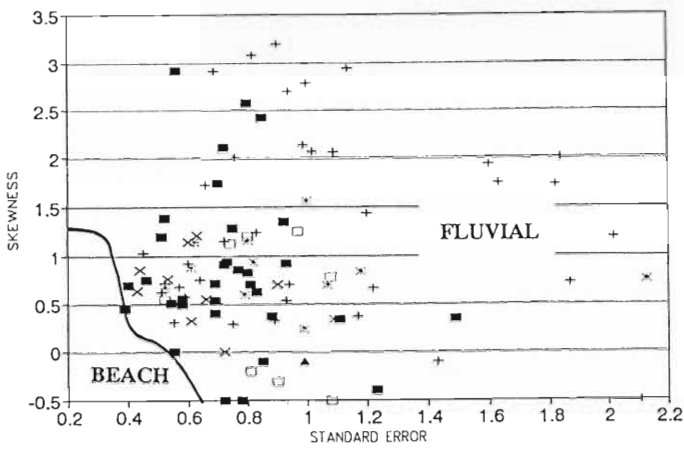
The only sample analysed from the **Ulundi Member** had a nearly symmetrical to negative skewness. In the **Eshowe Member**, the skewness ranged from very negative to extremely positive, with the majority falling in the extremely positive classification and only two samples showing negative skewness. The skewness of the **Kranskloof and Situndu Members** ranged from very negative to extremely positive, with a very positive mean. In the **Dassenhoek Member**, the skewness ranged from symmetrical to extremely positive, with a very positive mean, and no negative skewnesses calculated. The Skewness of the **Newspaper Member** was largely very positive with a spread to positive and extremely positive.

The Natal Group sandstones are very strongly positively skewed, as is well-illustrated in Fig. App-3.1. Of the 104 samples studied, only 11 (10,5%) were negatively skewed. This is an indication of fluvial deposition (McLaren, 1981). Friedman (1961) plotted skewness of samples against standard deviation (sorting), and produced a figure in which beach and fluvial deposits were easily distinguished. The author plotted the same parameters derived from the Natal Group samples (Fig. App-3.1a) and all the plotted points fell within the fluvial field defined by Friedman (1961). During the study, the following relationships were also plotted, with no clear patterns emerging: kurtosis vs mean largest diameter measured (Fig. App-3.1b); skewness vs mean largest diameter measured (Fig. App-3.1c); standard error (syn. standard deviation) vs mean largest diameter measured (Fig. App-3.1d); kurtosis vs standard error (Fig. App-3.1e) and kurtosis vs skewness (Fig. App-3.1f).

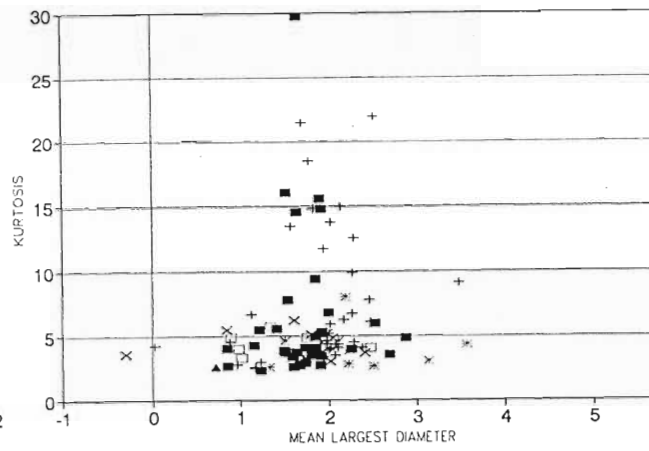
APP-3.3.4 FOURTH MOMENT

This moment, known as kurtosis, measures the normality of a distribution by comparing the sorting in the central part of the distribution with that at the extremes. The third and fourth

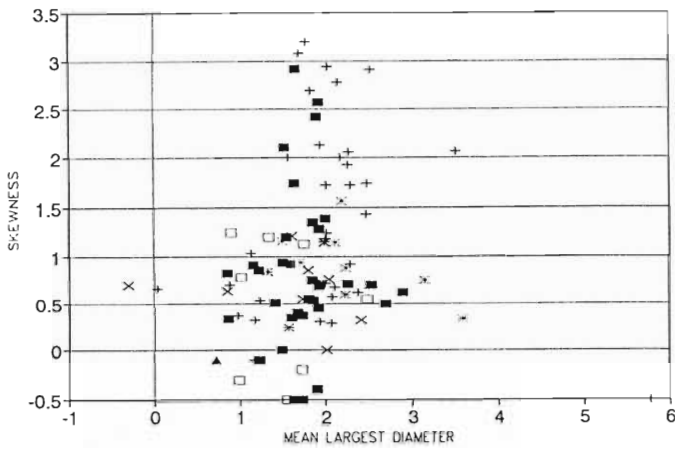
a. Skewness vs standard error
(dividing line after Friedman, 1961)



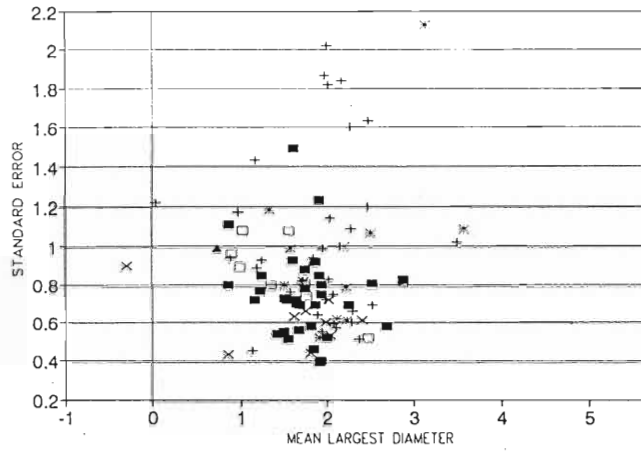
b. Kurtosis vs mean largest diameter



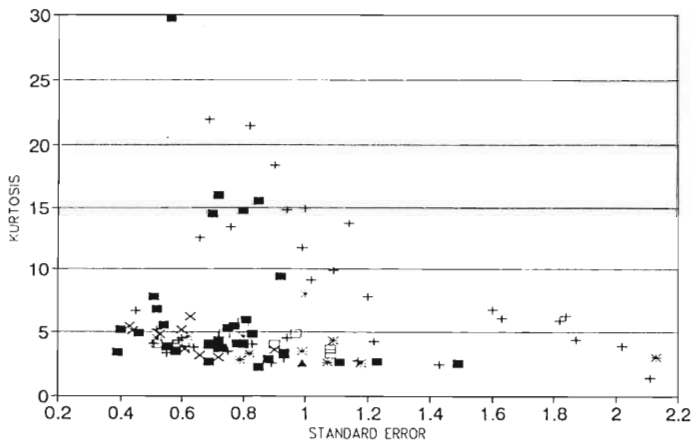
c. Skewness vs mean largest diameter



d. Standard error vs mean largest diameter



e. Kurtosis vs standard error



f. Kurtosis vs skewness

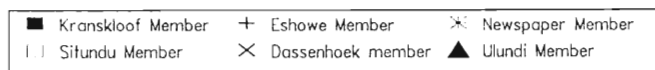
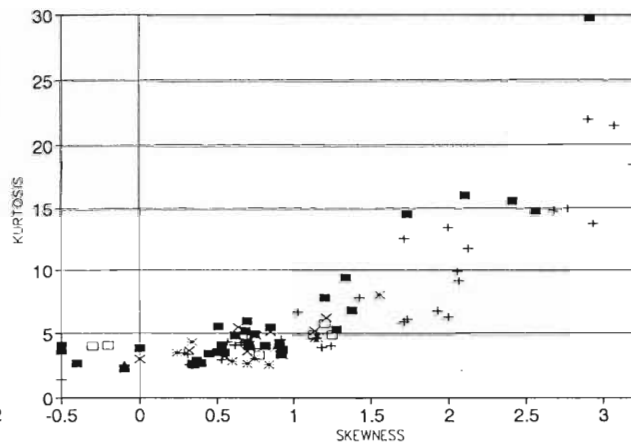


Fig. App-3.1 Grain-size moments graphs

moments are designed to measure the character of the tails of the distribution, and should therefore be very useful. However, they are seldom used diagnostically. Kurtosis is actually derived by dividing the fourth moment by the standard deviation raised to the fourth power (Friedman and Johnson, 1982).

$$\beta_{4\phi} = (\sum f (m_{\phi} - x_{\phi})^4) / (100 \times \delta^4)$$

It would seem that the kurtosis of a sample provides no useful information for the interpretation of grain-size interpretation (McLaren, 1981; Blatt *et al.* 1972). Mc Manus (1992) stated that this parameter is frequently calculated but not widely used, and is related to the dispersion and normality of the distribution.

APP-3.3.4.1 Kurtosis The results are summarised in Table App-3.3.

The verbal classification of Folk and Ward (1957) is used.

Only 16 (15%) of the 104 samples studied fell below the kurtosis figure of 3 (the lower limit of extreme leptokurtosis) and only one below the 1.5 figure (the lower limit of the "very leptokurtic" class). The extreme peakedness (leptokurtosis) indicates exceptionally good sorting of the central part of the distribution (Mc Manus, 1992).

LIST OF REFERENCES: APPENDIX 3.

- BLATT, H., MIDDLETON, G. AND MURRAY, R. 1972. *Origin of sedimentary rocks*. Prentice Hall Inc., New Jersey, 782 p.
- CHAYES, F. 1956. *Petrographic modal analysis: An elementary statistical appraisal*. J.Wiley and Sons, London, 113 p.
- DUNLEVY, J.N. AND MITCHELL, A.A. 1993. Modeplus: A program for computer-assisted modal measurement. *Computers and Geosciences* 20: 369-393.
- FOLK, R.L. 1959. *Petrology of Sedimentary rocks*. Hemphills, Austin, Texas, 154 p.
- FOLK, R.L. 1966. A review of grain-size parameters. *Sedimentology* 6: 73-93.
- FOLK, R.L. AND WARD, W.C. 1957. Brazos River Bar, a study in the significance of grain-size parameters. *Journal of Sedimentary Petrology* 27: 3-27.
- FRIEDMAN, G.M. 1958. Determination of sieve-size distribution from thin-section data for sedimentary studies. *Journal of Geology* 66: 394-416.
- FRIEDMAN, G.M. 1961. Distinction between dune, beach, and river sands from their textural characteristics. *Journal of Sedimentary Petrology* 31: 514-529.
- FRIEDMAN, G.M. 1962. On sorting, sorting coefficient, and the log-normality of the grain-size distribution of sandstones. *Journal of Geology* 70: 737-753.
- FRIEDMAN, G.M. AND JOHNSON, K.G. 1982. *Exercises in sedimentology*. John Wiley and Sons, New York, 208 p.
- HOLMES, A. 1930. *Petrographic methods and calculations*. Thomas Murby and Co., London, 515p.
- INMAN, D.L. 1952. Measures for describing the size distribution of sediments. *Journal of Sedimentary Petrology* 22: 125-145.
- JOHNSON, M.R. 1994. Thin section grain size analysis revisited. *Sedimentology* 41: 985-999.
- KRUMBEIN, W.C. AND PETTIJOHN, F.J. 1938. *Manual of sedimentary petrography*. Appleton-Century-Crofts Inc., New York, 549 p.
- MASON, C.C. AND FOLK, R.L. 1958. Differentiation of beach, dune and aeolian flat environments by size analysis, Mustang Islands, Texas. *Journal of Sedimentary Petrology* 28: 211-226.
- McLAREN, P. 1981. An interpretation of trends in grain-size measures. *Journal of Sedimentary Petrology* 51: 0611-0624.
- Mc MANUS, J. 1992. Grain size determinations and interpretation. In: *Techniques in Sedimentology*. (M. Tucker, Ed.) Blackwell Scientific Publications, Oxford, 63-85.
- MIDDLETON, G.V. 1967. On sorting, sorting co-efficients, and the lognormality of the grain-size distributions of sandstones - a discussion. *Journal of Geology* 70: 754-756.
- PETTIJOHN, F.J., POTTER, P.E. AND SIEVER, R. 1987. *Sand and sandstones*. Springer Verlag, 553 p.

- SWAN, D., CLAGUE, J.J. AND LUTERNAUER, J.L. 1978. Grain-size statistics I: Evaluation of the Folk and Ward graphic measures. *Journal of Sedimentary Petrology* 48: 863-878.
- SWAN, D., CLAGUE, J.J. AND LUTERNAUER, J.L. 1979. Grain-size statistics II: Evaluation of grouped moment measures. *Journal of Sedimentary Petrology* 49: 487-500.
- VAN DER PLAS, L. AND TOBI, A.C. 1965. A chart for judging the reliability of point-counting results. *American Journal of Science* 263: 87-90.

APPENDIX 4. PALAEOCURRENT ANALYSIS

APP-4.1 INTRODUCTION

The flow direction of the palaeocurrents which contributed to the deposition of each stratigraphic unit within the Natal Group depositional basin is a prime indicator of the palaeoslope of the basin and the provenance of the sediments, and an indicator of the depositional environment. An analysis of the palaeocurrent patterns also provides a better understanding of the depositional environment, and at least corroborate or modifies, previously-proposed basin margins. Palaeocurrent directions were obtained by measuring the orientation of current-produced, primary sedimentary structures such as planar and trough current-bedding, ripple marks, clast imbrication (only one occurrence) and parting lineation. Further light was thrown on the regional basin-fill patterns by data relating to changes in lithofacies and the basin geometry.

APP-4.2 PREVIOUS WORK

Matthews (1961) stated that the measurement of current bedding orientations within the Natal Group suggested that the source area for these rocks lay to the northeast. Rhodes and Leith (1967) measured some 350 palaeocurrent directions between Durban and Kranskop. The predominant direction in their Basal Zone (now Eshowe Member) was to the SW and SSW, with a component to the SSE near Mapumulo. They found difficulty in obtaining suitable cross-bedding in the highly-weathered Arkosic and Micaceous Zones.

Mathew (1971), in his study of what is now known as the Eshowe Member of the Durban

Formation in the Kloof Gorge near Durban, showed that the direction of sediment transport preserved within these rocks was from northeast to southwest.

Kingsley, (1975, Fig. 9) measured trough current-bedding directions in the area between Scottburgh and Port Shepstone, where he described sediment provenance to the north and northeast, parallel to the axis of the probably elongated basin. He showed, also, a secondary component towards the west and southwest.

Hobday and von Brunn (1979) recorded both trough and planar cross bedding orientations at Umdoni Park on the KwaZulu-Natal South Coast, which revealed a polymodal palaeocurrent pattern which nevertheless indicated a provenance to the northeast.

Roberts, (1981) determined palaeocurrent directions in the general vicinity of Durban, and suggested a provenance for the Eshowe Member, Situndu Member, Umlazi Formation and the Newspaper Member to the north and northeast. Palaeocurrent directions within the Kranskloof Member were generally to the southeast. Within the Dassenhoek Member, there were two palaeocurrent components, implying flow to the east and northeast, and to the southwest respectively. Roberts (1981) suggested that although the limited data showed a tendency towards polymodality, there was a strong indication of a southeastward direction of transport, with a relatively high mean angular deviation.

It is interesting to note that Hobday *et al.* (1971) recorded a northeast-to-southwest palaeocurrent direction for the Msikaba Formation of Pondoland. This is essentially the same as for the Natal Group, and it would be expected to be different, especially in the light of the marine origin postulated for the Msikaba Formation by virtually all who have written about this unit.

APP-4.3 METHODS

APP-4.3.1 SAMPLING PROCEDURES

The palaeocurrent directions used in this study were determined by the author, primarily during the measurement of stratigraphic sections and outcrop mapping of selected areas. The orientation of a) foresets of planar and trough cross-beds, b) asymmetric ripple-marks, and c) clast imbrication in coarse conglomerates were recorded. Care was taken to ensure that apparent dip angles and azimuths, as exposed on vertical rock faces, were not measured. At many localities, it was impossible to obtain a meaningful palaeocurrent measurement on the vertical rock-face, and it was considered preferable to present a few accurate measurements, rather than a multitude of readings of questionable validity. A further reason for the paucity of data in some areas is that erosion has removed large portions of the Natal Group, especially the Newspaper Member which is susceptible to erosion as it is not overlain by a resistant unit, and this has militated against obtaining a complete picture of the palaeocurrent domain. There are therefore insufficient palaeocurrent readings for a rigorous statistical analysis.

APP-4.3.2 ANALYSIS OF DATA

The measurements were recorded on an electronic spreadsheet, and the various parameters derived by applying formulae as discussed below. Rose diagrams were plotted on an HP 7475A plotter, using a programme devised by L.G. Wolmarans⁴. In this programme, the

⁴ Council for Geoscience, Silverton

compass is divided into 10° segments. These were then drawn onto the palaeocurrent maps of the various stratigraphic units. The advantages of using a non-linear frequency scale (Nemec, 1988) could not be achieved, as the available software could not be adapted to produce rose diagrams with a logarithmic frequency scale.

Moving averages (Lindholm, 1987) were calculated, where sufficient data were available, and plotted on the same maps as the rose diagrams, except for the Eshowe Member, where, because of the data density, a separate map was drawn to avoid congestion. These maps are presented as figures accompanying the discussion of results for each stratigraphic unit.

Where the Natal Group rocks have been tilted more than 3° by later tectonic activity, the affected measurements were corrected to zero bed-dip and the original orientation of the structure obtained, using a computer programme devised by Cole and Basson (1986) on a computer diskette provided by D. Cole⁵.

Pettijohn *et al.* (1987) advocated the plotting of an average palaeocurrent direction (preferably the vector mean) rather than a rose diagram, for each locality, except in the case of markedly bimodal or polymodal distribution. Graham (1988), on the other hand, advocated the drawing of rose diagrams. Rose diagrams (with vector mean azimuth) were prepared for each significant locality, as these project a visual image of the distribution, which, in the author's opinion, is far preferable to any statistical treatment.

⁵

Council for Geoscience, Belville

From a large number of statistical parameters proposed by previous workers, the following vector statistics were considered important and hence calculated, using a spreadsheet programme, and are presented in Table App-4.1.

APP-4.3.2.1 Vector Mean (Sanderson, 1973, Tucker, 1988; Lindholm, 1987)

$$\Theta = \text{Arctan} (\sum_{i=1} \text{Sin}\Theta / \sum \text{Cos}\Theta)$$

Curry (1956) called this the azimuth of the resultant vector, whereas Cole and Basson (1986) called it the mean azimuth. It reflects the preferred orientation, and the vector mean of a population of palaeocurrent directions is a satisfactory average for all except markedly bimodal distributions, in which case the midpoints of the two modes should be plotted (Pettijohn *et al.* 1987). Curry (1956,) further stated that vector direction is a measure of the central tendency of the distribution, whereas the mean is very sensitive to the choice of origin. It is comparable to the mean but has the advantage of being independent of the reference direction and origin.

APP-4.3.2.2 Vector Strength, Vector Magnitude, Consistency ratio

Curry (1956, p. 119) and Graham (1988, p. 43) described the "magnitude of the resultant vector",

$$R = [(\sum \text{Sin}\Theta)^2 + (\sum \text{Cos}\Theta)^2]^{1/2}$$

Cole and Basson (1986, p. 81) termed this parameter the "magnitude of the mean azimuth", while Lindholm (1987, p. 47) referred to it as the "Vector Magnitude", and stated that this should be expressed as a percentage (also known as the "Consistency Ratio") to facilitate comparison between samples. Sanderson (1973, p. 1096) stated that the "Vector Strength" (his term for "Vector Magnitude" after normalising for sample size) indicated the dispersion

about the vector mean in terms of the length (or magnitude) of the resultant vector. Roberts (1981) also referred to vector strength, but applied a factor of $1/n$ to the formula so that it would be less than 1 - an important consideration in calculating the Mean Angular Deviation where the square root of $2(1-\text{vector strength})$ is a key to the calculation. Curray (1956) expressed this parameter as a percentage, $L = (R/\Sigma n) \times 100$, and stated that it is a sensitive measure of dispersion, comparable to standard deviation or variance, as it is independent of choice of origin. It can thus be used to estimate the degree of preferred orientation, and hence gauge the environment of deposition of the palaeocurrents measured. Cole and Basson (1986, p. 81) also referred to this as the "Consistency Ratio". Thamm (1988) stressed the importance of the consistency ratio in interpreting the palaeoenvironment.

Lindholm (1987, p. 47) stated that high consistency ratio values indicate a clustering of readings about the vector mean (i.e. a low dispersion), and are produced by individual measurements trending generally in the same direction. Scatter is indicated by low values.

APP-4.3.2.3 Mean Angular Deviation, Standard Deviation Roberts (1981, p. 62) and Graham (1988, p. 45) gave the formula for the mean angular deviation.

Roberts: $S^\circ = [2(1-R)]^{1/2} \times 180/\pi$ in degrees

Graham: $S = [2(1-R)]^{1/2}$ in radians

In both cases, R must be less than 1, or $1-R$ will be negative, and it will be impossible to derive the square root.

It will be noticed that the consistency ratio in Table App-4.1 is 100x the vector strength, because it is expressed as a percentage. Roberts' vector strength formula, utilising $1/n$,

ensures that the value of R remains less than 1, and was therefore used by the present author. Graham (1988) indicated that the consistency ratio behaves mostly in the same way as the standard deviation of a normal distribution, but is not its circular analogue.

Cole and Basson (1986, p. 81) gave the formula for Standard Deviation, and pointed out that it is useful because it indicates whether the deposit under study is proximal or distal. However, they do not indicate how the results may be interpreted. Pettijohn *et al.* (1987) noted that the Standard Deviation is a convenient measure of dispersion, and that the value decreases with an increasing number of observations.

The author calculated both Mean Angular Deviation (Roberts, 1981) and Standard Deviation (Cole and Basson, 1986). The results are included in Table App-4.1.

APP-4.3.2.4 Rayleigh Test: Curray (1956, Fig. 4) and Lindholm (1987, Fig. 2.7) discussed the Rayleigh Test for preferred orientation of circular data. The vector magnitude as a percentage (or the consistency ratio) is plotted against the number of observations for the sample. If the result plots above the 0,05 level of significance line, the sample is considered to be from a population with a preferred orientation.

Only population No. 28, to the northeast of Wartburg, has any suggestion of opposed palaeocurrent directions which could conceivably be used to invoke a tidal environment. However, considering a braided stream environment, with a fairly wide area of reference for the rose diagrams, it is not thought to be strange that such a palaeocurrent direction pattern was recorded.

APP-4.3.2.5 Picard and High Test: Graham (1988), referring to Picard and High (1968), stated that, for polymodal distributions, where vector statistics are not appropriate, a simpler, semi-quantitative technique may be used to express preferred orientation. Using this technique, a compass is divided into 12 x 30° segments, and the mean number of occurrences per interval, as well as the arithmetic standard deviation, calculated. Those intervals which contain a number of palaeocurrent measurements in excess of one standard deviation above or below the mean, represent prominent modes or nodes, respectively. Intervals within one standard deviation are considered to be quantitatively indistinguishable from random distribution. The present author applied this method to each palaeocurrent population, using a Casio FX 82-B pocket calculator, and the results are presented in Table App-4.1 under the Picard and High column.

APP-4.3.3 DISCUSSION OF RESULTS

APP-4.3.3.1 Eshowe and Ulundi Members: The palaeocurrents in the Eshowe and Ulundi Members are very strongly oriented from the northeast to the southwest, as illustrated in Fig. APP-4.1. Both the rose diagrams and the accompanying vector means illustrate this. In the vicinities of Pietermaritzburg and Greytown, and the area in between, there is a fairly strong northwest to southeast component, which is probably due to the basement highs extending northeastwards from Pietermaritzburg and Greytown respectively (Fig. 3.15). The northwesterly component is also reflected in the moving average map (Fig. APP-4.2). The consistency ratio (Table App-4.1) is generally high to medium, indicating a generally preferred orientation, with some dispersion of currents which one would expect in an environment of a braided river in an elongate trough. Populations 7, 8 and 9 (Table App-4.1)

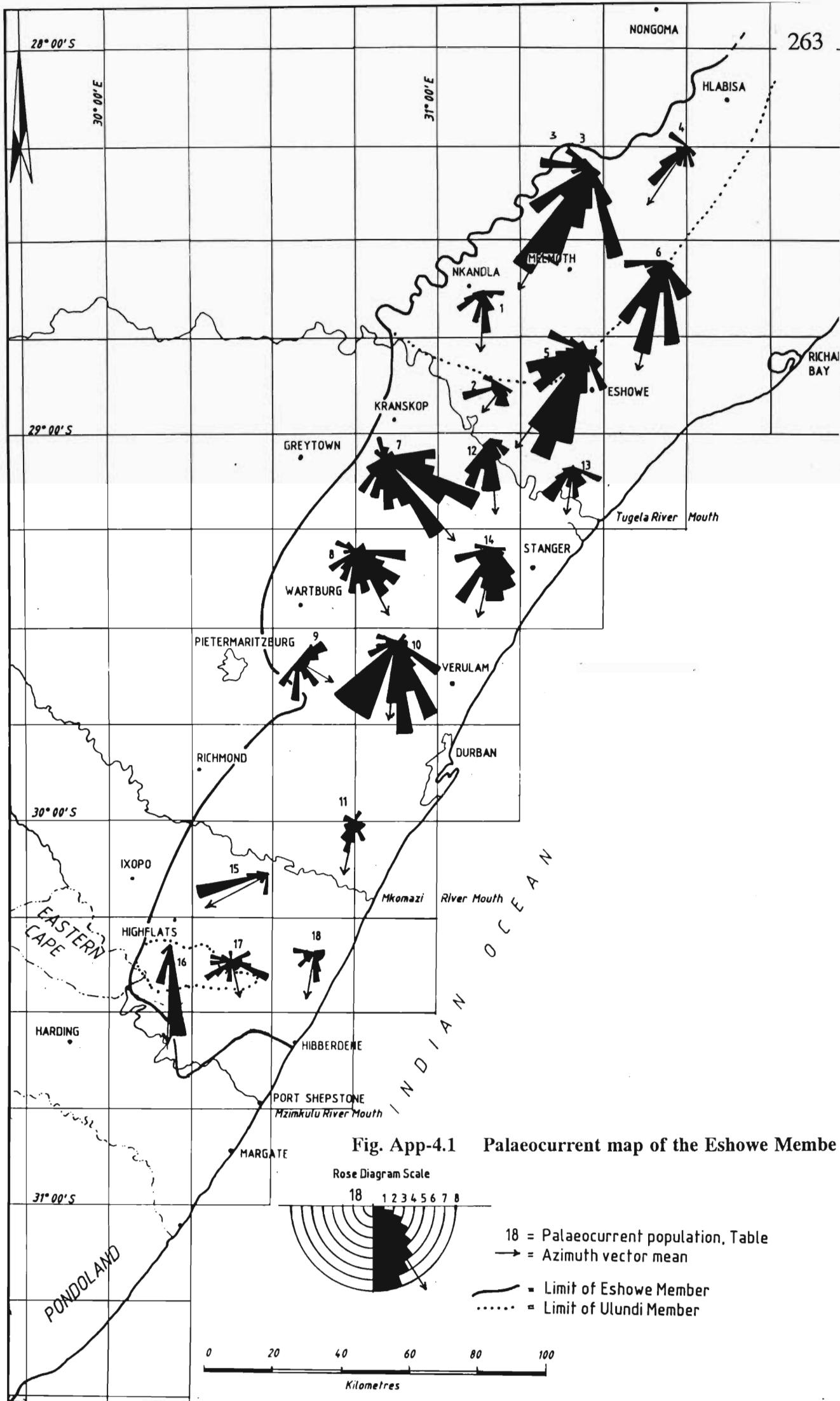


Fig. App-4.1 Palaeocurrent map of the Eshowe Member

Rose Diagram Scale

18 1 2 3 4 5 6 7 8

18 = Palaeocurrent population, Table

→ = Azimuth vector mean

— = Limit of Eshowe Member

..... = Limit of Ulundi Member

0 20 40 60 80 100
Kilometres

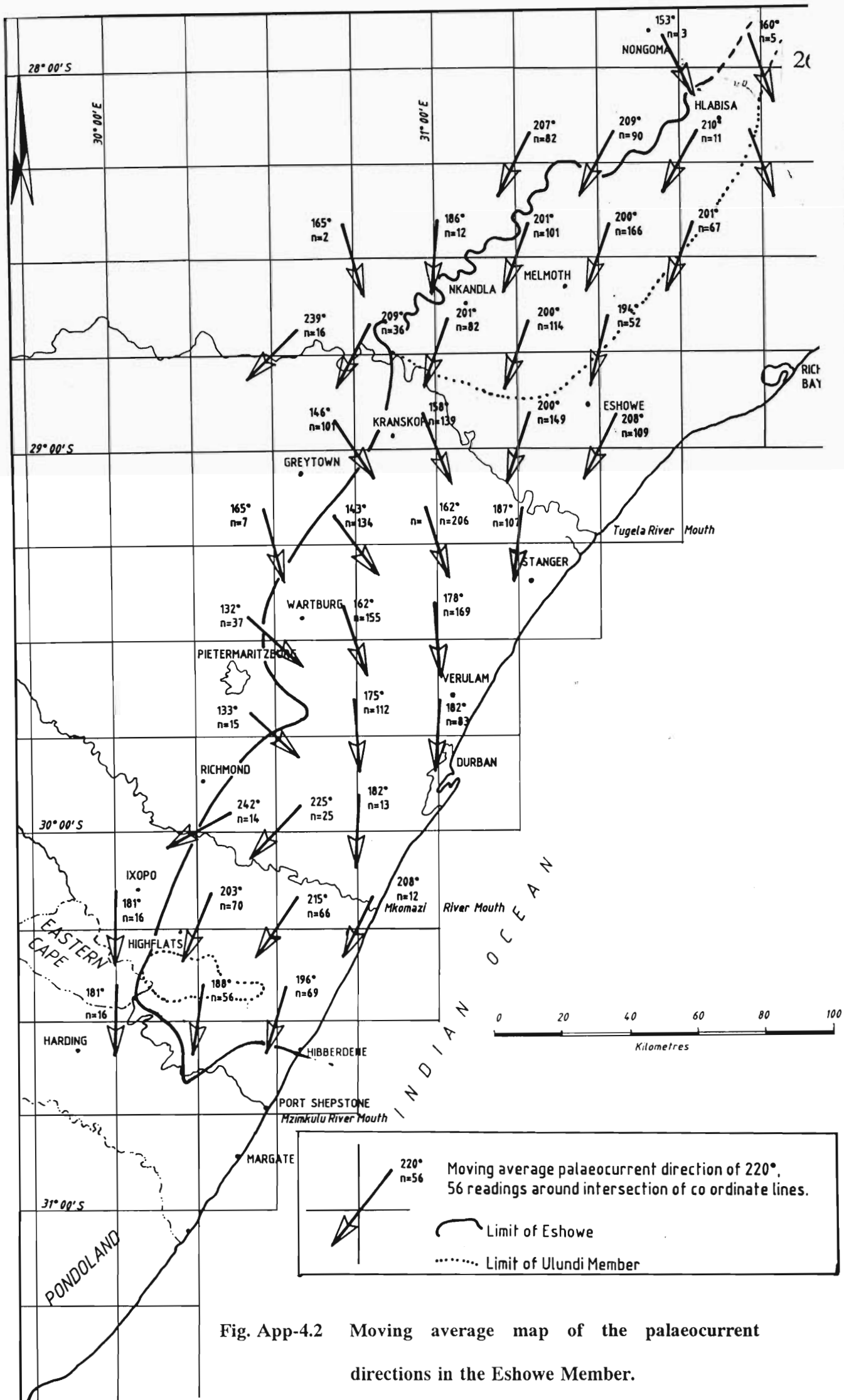


Fig. App-4.2 Moving average map of the palaeocurrent directions in the Eshowe Member.

POPULATION REFERENCE	GEOREFERENCE	READINGS	VECTOR MEAN	VECTOR STRENGTH	CONSISTENCY RATIO %	STD. DEVN. °	MEAN ANGULAR DEVIATION °	RAYLEIGH TEST	PICARD & HIGH 1968	STRATIGRAPHY
1	2830DB	25	182	0,697	69,7	36,9	44,6	+	Pref	Eshowe & Ulundi
	2831CA, CB									
2	2830DD	24	218	0,68	68	45	45,7	+	Pref	Eshowe
	2831CC									
3	2831AD	77	211	0,75	75	31	40,2	+	Pref	Eshowe
4	2831BB	21	214	0,76	76	36	39,2	+	Pref	Eshowe
	2831BC									
5	2831CD	81	217	0,69	69	40	45,3	+	Pref	Eshowe
6	2831DA	52	194	0,83	83	22	33	+	Pref	Eshowe
7	2930BB	79	139	0,64	64	44	48,3	+	Pref	Eshowe
8	2930BC	55	152	0,62	62	45	50	+	Pref	Eshowe
	2930BD									
9	2930DA	30	121	0,57	57	42	53,3	+	Pref	Eshowe
10	2930DB	77	185	0,73	73	29	41,8	+	Pref	Eshowe
11	2930DC	19	192	0,66	66	25	47,3	+	Pref	Eshowe
	2930DD									
	3030BA									
12	2931AA	32	177	0,86	86	16	30,1	+	Pref	Eshowe
13	2931AB	28	187	0,77	77	32	39,2	+	Pref	Eshowe
14	2931AC	50	194	0,77	77	28	39,1	+	Pref	Eshowe
15	3030AB	14	242	0,89	89	71	26,7	+	Pref	Eshowe
16	3030AC	16	181	0,98	98	3	12,4	+	Random	Eshowe
17	3030AD	31	167	0,32	32	60	67	+	Bim	Eshowe
18	3030BC	18	189	0,53	53	50	55,8	+	Bim	Eshowe
	3030DA									

Pref
Random
Bim
Poly

= exhibits preferred orientation
= exhibits no preferred orientation
= Exhibits bimodal orientation
= Exhibits polymodal orientation

Table App-4.1 Natal Group Palaeocurrent statistics (Sheet 1 of 3)

POPULATION REFERENCE	GEOREFERENCE	READINGS	VECTOR MEAN	VECTOR STRENGTH	CONSISTENCY RATIO %	STD. DEVN*	MEAN ANGULAR DEVIATION*	RAYLEIGH TEST	PICARD & HIGH 1968	STRATIGRAPHY
19	2831AD	34	192	0,83	83	20	33,17	+	Pref	Newspaper
	2831CB									
	2831DA									
20	2831CD	44	202	0,74	74	25	41,0	+	Pref	Newspaper
	2830DD									
21	2930BD	27	179	0,73	73	31	42,2	+	Pref	Newspaper
	2931AB									
	2931AC									
22	2930DC	38	171	0,51	51	51	56,5	+	Bim	Newspaper
	2930DD									
23	3030AA	34	213	0,58	58	39	52,3	+	Random	Newspaper
	3030AB									
	3030AC									
	3030BA									
	3030BC									
	3030DA									
24	3030CB	13	245	0,77	77	69	38,7	+	Pref	Newspaper
25	2930BB	9	214	0,86	86	34	30,4	+	Random	Tulini
26	2930BB	46	197	0,73	73	28	42,4	+	Pref	Situndu
	2930BC									
	2930BC									
	2930DB									
	2930DC									
	2931AA									
	3030AB									
27	2830DD	25	168	0,62	62	26	50,1	+	Pref	Kranskloof

Table App-4.1 Natal Group Palaeocurrent statistics (Sheet 2 of 3)

POPULATION	GEOREFERENCE	READINGS	VECTOR MEAN	VECTOR STRENGTH	CONSISTENCY RATIO %	STD. DEVN. °	MEAN ANGULAR DEVIATION	RAYLEIGH TEST	PICARD & HIGH, 1968	STRATIGRAPHY
	2831CD									
	2930BB									
	2931AA									
	2931AB									
	2830DD									
28	2930BD	20	188	0,30	29	53	68,1	+	Poly	Kranskloof
	2931AC									
29	2930DA	25	157	0,56	56	32	54	+	Pref	Kranskloof
	2930DB									
30	2930DC, DD	17	182	0,41	41	56	62,1	+	Pref	Kranskloof
	3030BA, BC									
31	3030AC	24	206	0,67	67	46	46,5	+	Pref	Kranskloof
	3030AD									
32	2831AD	10	194	0,86	86	11	30,3	+	Pref	Westville
33	2930DD	3	115	0,83	83	46	33,4		Random	Westville
34	3030CB	1	277							Msikaba
35	3030DA	6	125	0,95	95	63	17,7	+	Pref	Msikaba
36	3130AA	7	203	0,90	90	21	26,0	+	Pref	Msikaba
37	2930DC	6	145	0,98	98	23	11,1	+	Pref	Dassenhoek
38	3030CB	1	281							Dassenhoek
39	2831BB	16	180	0,89	89	14	26,9	+	Pref	Newspaper
40	2830DD	1	180							Dassenhoek
41	2930DC	1	200							Westville
42	2930BC	1	230							Dassenhoek

Table App-4.1 Natal Group Palaeocurrent statistics (Sheet 3 of 3)

have a greater dispersion than the others in the area north of the line between Durban and Pietermaritzburg, which can be seen in the rose diagrams in Fig. APP-4.1. Population 17, in the far south of the area (Fig. APP-4.1, Table App-4.1) has a random distribution, and possibly indicates interference of the Dweshula High (Fig. 1.1).

The Rayleigh Test for preferred orientation of circular data (Curry, 1956) was positive for all populations sampled. The Picard and High (1968) test also indicated that all samples display a preferred orientation.

APP-4.3.3.2 Kranskloof Member: Orientation of the palaeocurrent directions measured in the Kranskloof Member is strongly from north to south, but the dispersion is somewhat higher than that of the Eshowe Member, as indicated by a lower consistency ratio (Table App-4.1) and illustrated in Fig. APP-4.3. The moving averages of the palaeocurrent directions are also less consistent, indicating a greater variation (Fig. APP-4.3). If the environment of deposition was, as is suggested in Chapter 6., a braidplain on which the Eshowe Member sediments were reworked during southward redistribution, then the palaeocurrent directions would not be expected to be as strongly preferentially oriented, as the influence of the elongate basin would be reduced. The isopach map (Fig. 3.32) shows no strong patterns which might influence the palaeocurrent directions, apart, of course, from the basin margins and the generally elongate shape from northeast to southwest. The consistency ratios (Table App-4.1) are low, reflecting the dispersion around the vector means.

The Rayleigh Test for preferred orientation of circular data (Curry, 1956) was positive for all but one of the populations sampled. This population, No. 28, indicated a random

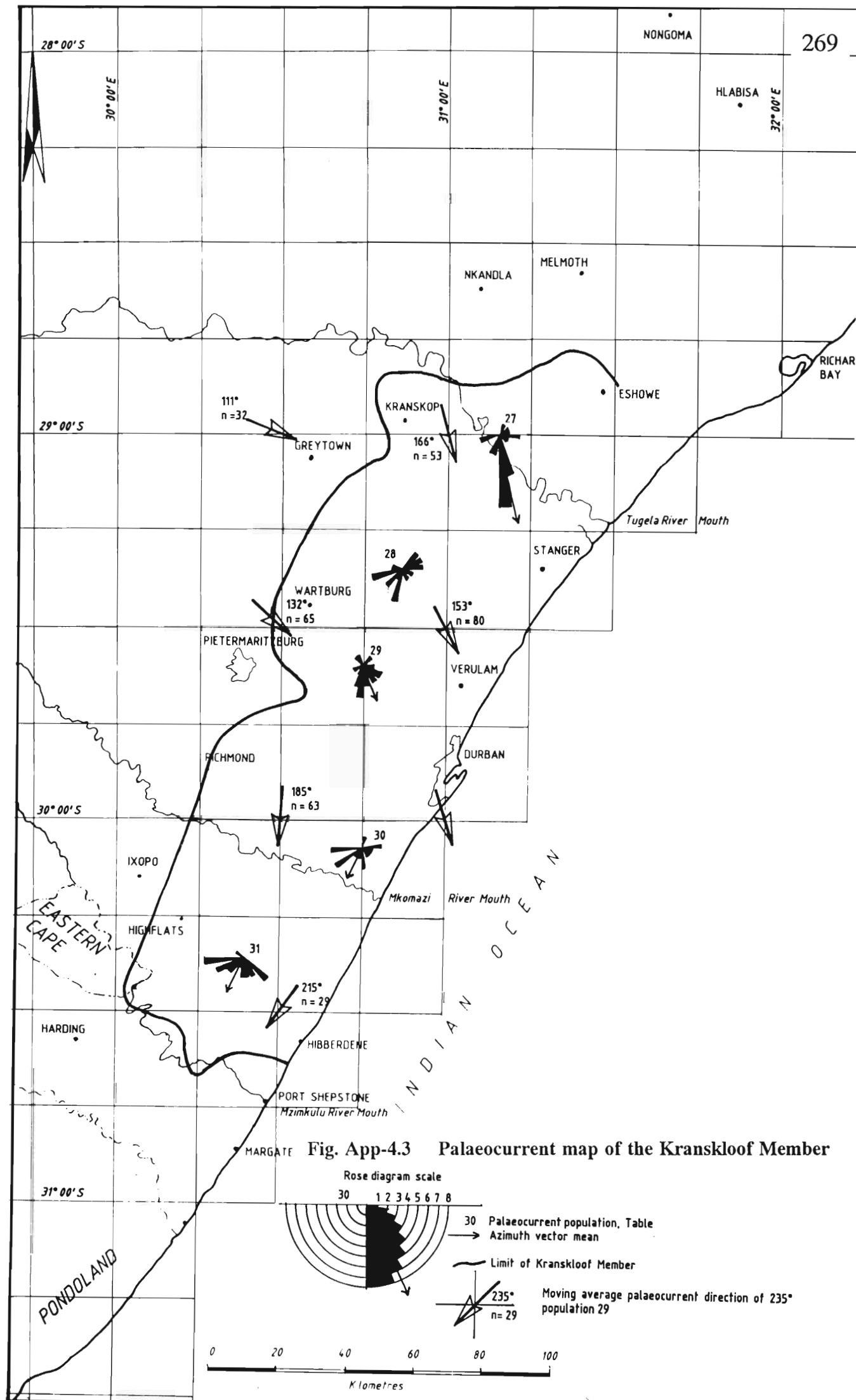


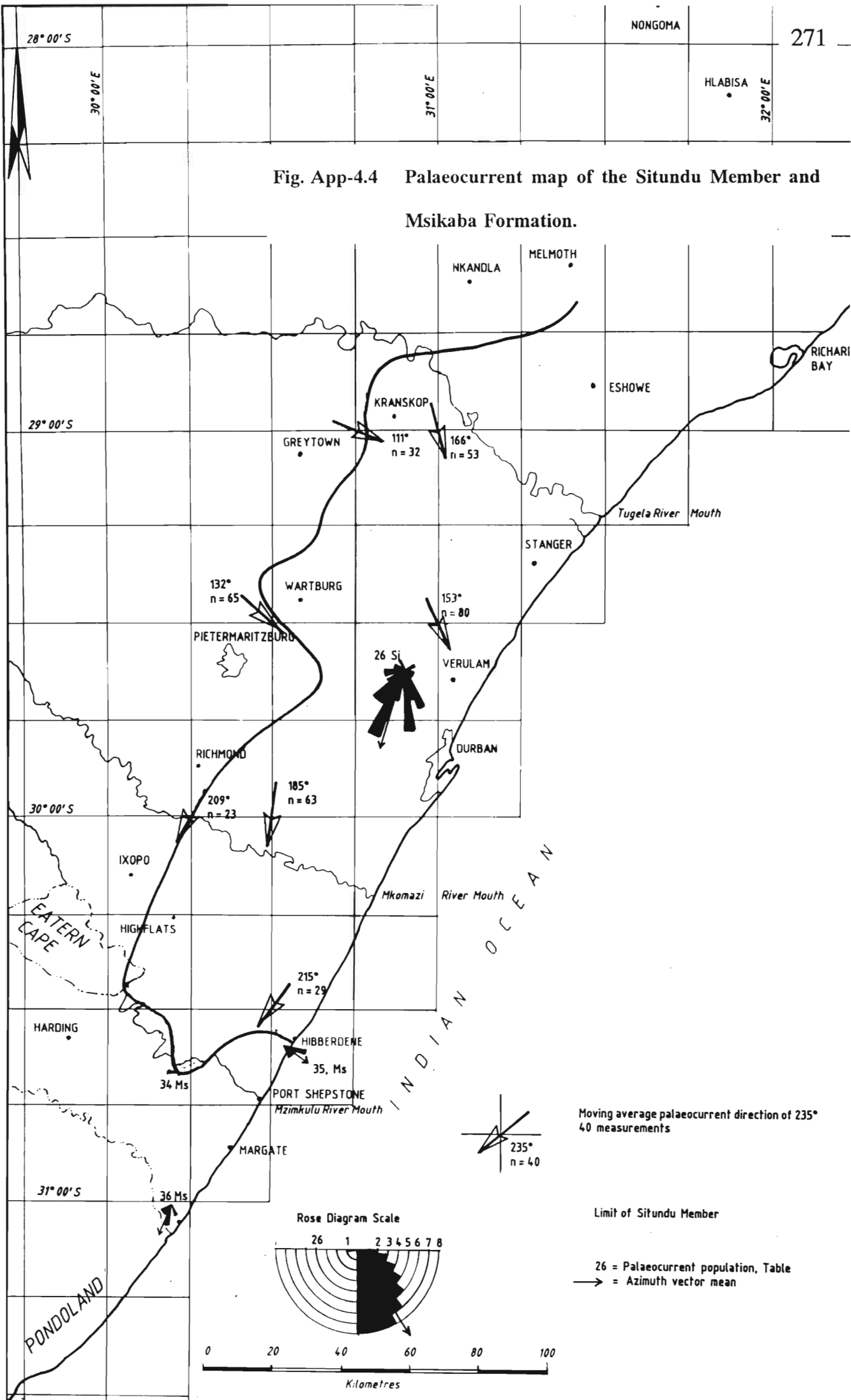
Fig. App-4.3 Palaeocurrent map of the Kranskloof Member

distribution. The Picard and High (1968) test also indicated that all samples except for population No. 28 (which is polymodal) have a preferred orientation.

APP-4.3.3.3 Situndu Member: Palaeocurrent data for this unit was scarce, and therefore all the recorded readings were plotted as one rose diagram (Fig. APP-4.4). This is suggestive of a fairly strong north-to-south palaeocurrent direction with a low spread around the vector mean (Table App-4.1), which is borne out by the fairly high consistency ratio (Table App-4.1). The moving averages (Fig. APP-4.4) reveal a northwest-to-southeast palaeoflow direction in the north, changing to a northeast to southwest direction in the south. The isopach map of the Situndu Member (Fig. 3.36) reveals a northeast to southwest trough in the north and isolated deepened portions near Durban, which could have influenced the flow of palaeocurrents in the region. The Rayleigh Test was positive, as was the Picard and High test.

APP-4.3.3.4 Dassenhoek Member: The very sparse palaeocurrent directions derived from the measurement of primary sedimentary structures in the Dassenhoek Member, give an indication of palaeoflow generally from northwest to southeast near Durban, and from east to west in the far south of the basin (Fig. 3.44, Table App-4.1). The isopach map of the Dassenhoek Member (Fig. 3.41) shows a generally centripetal thickening of the member. The palaeocurrents measured, although too sparse for any measure of statistical treatment, do at least show a palaeocurrent flow from north to south. Of the measurements taken, the consistency ratio is high (Table App-4.1) indicating a small spread around the vector mean. The Rayleigh Test for preferred orientation of circular data (Curry, 1956) was positive, and the Picard and High (1968) test indicated a preferred orientation (Table App-4.1).

Fig. App-4.4 Palaeocurrent map of the Situndu Member and Msikaba Formation.



APP-4.3.3.5 Tulini Member: Only in the region between Wartburg and Greytown was it possible to obtain significant numbers of palaeocurrent measurements. The prevailing palaeocurrent direction, as indicated by the sparse observations made, was from the northeast to the southwest (Fig. APP-4.5, Table App-4.1), which parallels the axis of the basin as reflected by the isopach map of this unit (Fig. 3.43).

The vector mean of the nine measurements is 214° , and the spread of readings around the vector mean is low, as reflected by the high consistency ratio. The Rayleigh Test for preferred orientation of circular data (Curry, 1956) indicated a preferred orientation, but the Picard and High (1968) test suggested random orientation of the palaeocurrent directions. The rose diagram has a general northeast to southwest direction, but there is a fairly wide spread around the vector mean. The anomalous situation is undoubtedly due to the sparsity of observations.

APP-4.3.3.6 Newspaper Member: The observations in this unit were too sparse for the preparation of rose diagrams, and so the author plotted the vector means (Fig. APP-4.6). There is a general north-northeast to south-southwest palaeocurrent direction, with a northwest to southeast component as individual measurements locally. The moving averages calculated indicate a north-northeast to south-southwest palaeocurrent direction.

APP-4.3.3.7 Conclusion: Every unit of the Natal Group has a strong, overall north-to-south palaeocurrent direction orientation. This is corroborative evidence for a fluvial deposition of the Natal Group (see Fuller, 1985).

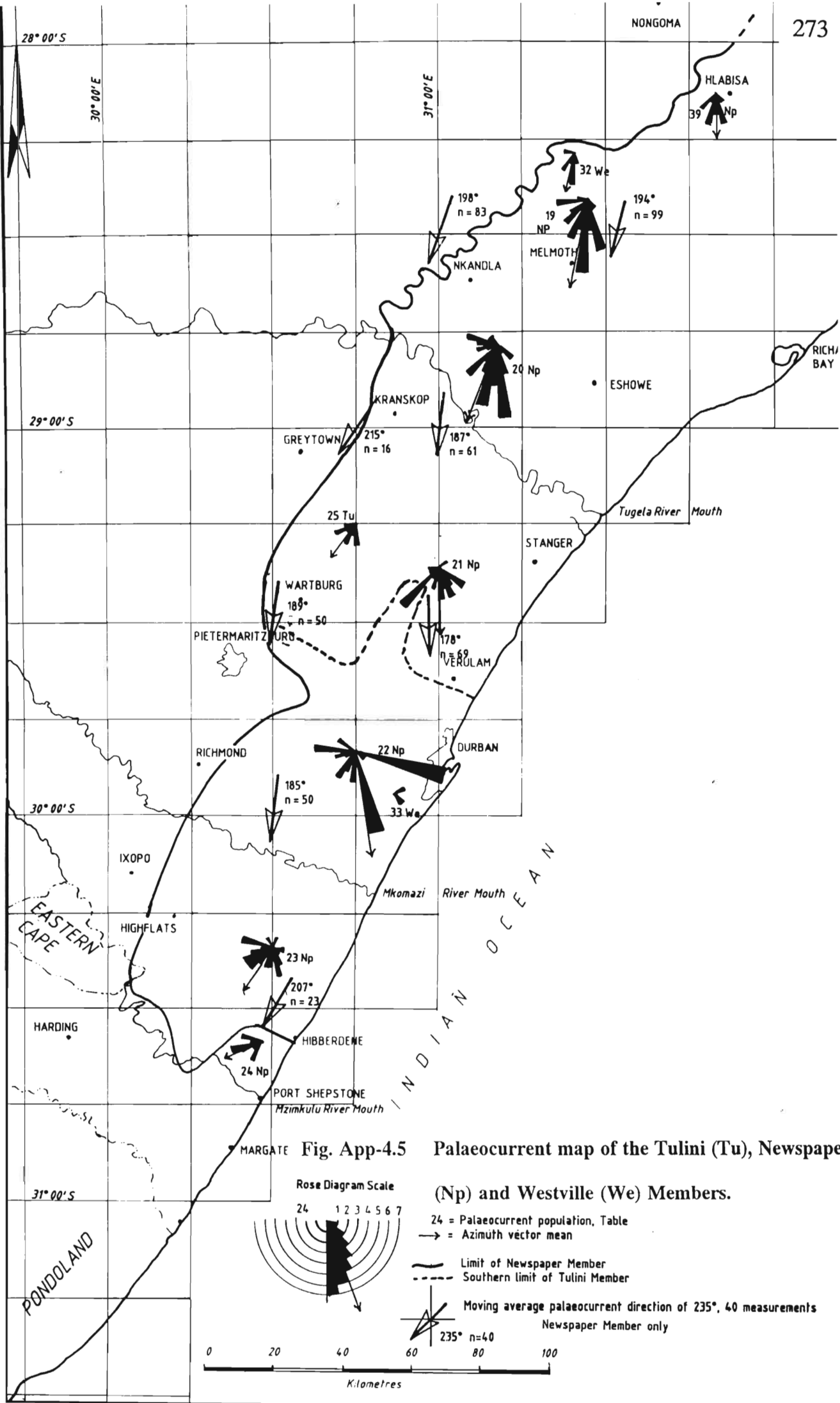


Fig. App-4.5 Palaeocurrent map of the Tulini (Tu), Newspaper (Np) and Westville (We) Members.

Rose Diagram Scale

24 1 2 3 4 5 6 7

24 = Palaeocurrent population, Table
 → = Azimuth vector mean

— Limit of Newspaper Member
 - - - Southern limit of Tulini Member

↗ Moving average palaeocurrent direction of 235°, 40 measurements Newspaper Member only

235° n=40

0 20 40 60 80 100
 Kilometres

HLABISA

32° 00' E

28° 00' S

30° 00' E

31° 00' E

183°
n=7

NKANDLA

MELMOTH

ESHOWE

RICHARD BAY

29° 00' S

111°
n=32

265° / 1

178° / 5

GREYTOWN

KRANSKOP

166°
n=53

125° / 1

68° / 3

152° / 4

250° / 1

90° / 1

95° / 1

63° / 4

227° / 7

180° / 2

155° / 1

204° / 10

Tugela River Mouth

STANGER

132°
n=65

WARTBURG

250° / 3

169° / 2

150° / 1

PIETERMARITZBURG

113° / 2

380° / 1

150° / 1

153°
n=80

60° / 1

119° / 3

200° / 14

168° / 3

140° / 1

181° / 3

98° / 4

185° / 1

140° / 2

RICHMOND

225° / 2

103° / 3

DURBAN

163°
n=40

30° 00' S

209°
n=23

IXOPO

185°
n=63

215° / 1

202° / 2

Mkomazi River Mouth

EASTERN CAPE

HIGHFLATS

234° / 9

194° / 8

215°
n=29

248° / 14

HARDING

193° / 7

170° / 1

138° / 2

HIBBERDENE

Fig. App-4.6 Map of the mean and moving averages of the palaeocurrent directions in the Kranskloof Member.

Map of the mean and moving averages of the palaeocurrent directions in the Kranskloof Member.

PORT SHEPSTONE
Mzimkulu River Mouth

MARGATE

Limit of Kranskloof Member

31° 00' S

PONDOLAND

225° is mean palaeocurrent direction of 15 readings

225° / 15

Moving average palaeocurrent direction of 225°
40 measurements around intersection of co-ordinate lines.

225°
n=40



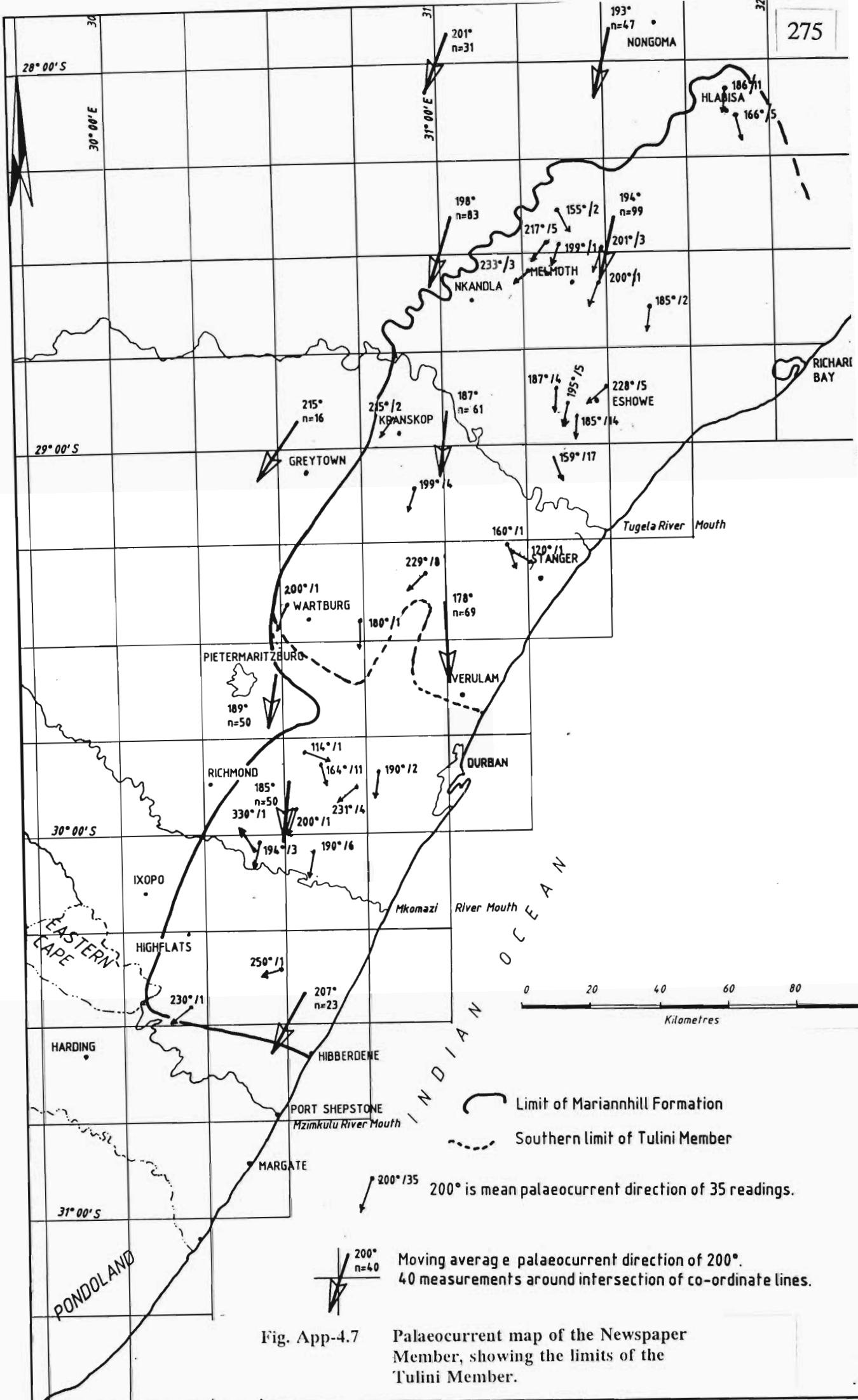


Fig. App-4.7 Palaeocurrent map of the Newspaper Member, showing the limits of the Tulini Member.

LIST OF REFERENCES: APPENDIX 4

- COLE, D.I. AND BASSON, E. 1986. Hewlett-Packard HP-67 Program to correct palaeocurrent data for structural dip and compute vector statistics. *Annals of the Geological Survey of South Africa* 20: 12 p.
- CURRAY, J.R. 1956. The analysis of two-dimensional orientation data. *Journal of Geology* 64: 117-131.
- FULLER, A.O., 1985. A contribution to the conceptual modelling of pre-Devonian fluvial systems. Presidential address. *Transactions of the Geological Society of South Africa* 88: 189-194.
- GRAHAM, J. 1988. *Collection and analysis of field data*. In: Techniques in sedimentology. (M. Tucker, Ed.) Blackwell Scientific Publications, 5-62.
- KINGSLEY, C.S. 1975. A new stratigraphic classification implying a lithofacies change in the Table Mountain Sandstone in southern Natal. *Transactions of the Geological Society of South Africa* 78: 43-55.
- LINDHOLM, R. 1987. *A practical approach to sedimentology*. Allen and Unwin, London, 276 p.
- MATHEW, D. 1971. A palaeoenvironmental study of the basal zone Table Mountain Sandstone at Kloof Gorge. *Petros* 3: 6-17.
- MATTHEWS, P.E. 1961. Slump structures in the Table Mountain Series of Natal. *Transactions of the Geological Society of South Africa* 64: 55-69.
- NEMEC, W. 1988. The shape of the rose. *Sedimentary Geology* 59: 149-152.
- PETTIJOHN, F.J., POTTER, P.E. AND SIEVER, R. 1987. *Sand and sandstones*. Springer Verlag, 553 p.
- PICARD, M.D. AND HIGH, L.J. 1968. Shallow marine currents on the early Triassic Wyoming Shelf. *Journal of Sedimentary Petrology* 38: 411-423.
- RHODES, R.C. AND LEITH, M.J. 1967. Lithostratigraphic zones in the Table Mountain Series of Natal. *Transactions of the Geological Society of South Africa* 70: 15-28.
- ROBERTS, D.L. 1981. The stratigraphy and sedimentology of the Natal Group in the Durban area. *Unpublished M.Sc thesis, University of Natal, (Durban), 118 p.*
- SANDERSON, D.J. 1973. Some inference problems in palaeocurrent studies. *Journal of Sedimentary Petrology* 43: 1096-1100.
- THAMM, A.G., 1988. Contributions to the geology of the Table Mountain Group. *Unpublished M.Sc thesis, Department of Geology, University of Cape Town. 102 p.*
- TUCKER, M.E. 1988. *Techniques in sedimentology*. Blackwell Scientific publications, Oxford, 388 p.

APPENDIX 5 CLAST SHAPE PARAMETER GRAPHS

Sampling Locality B

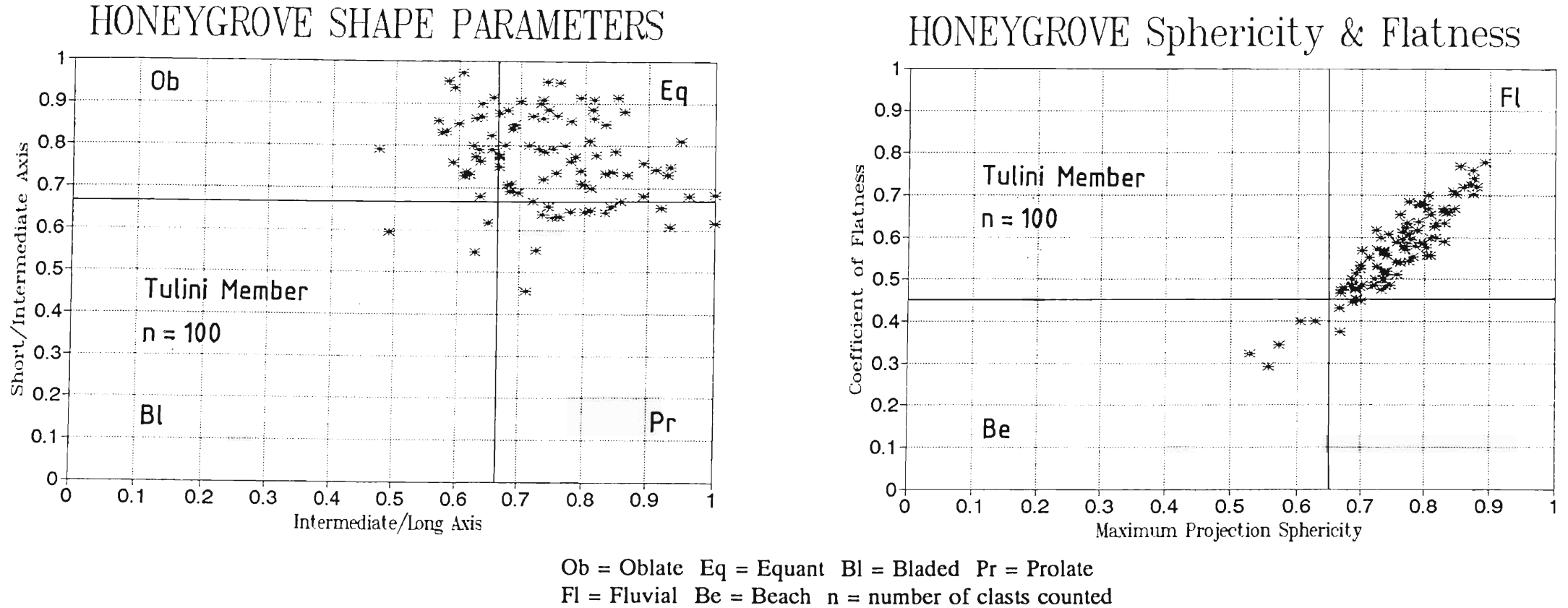
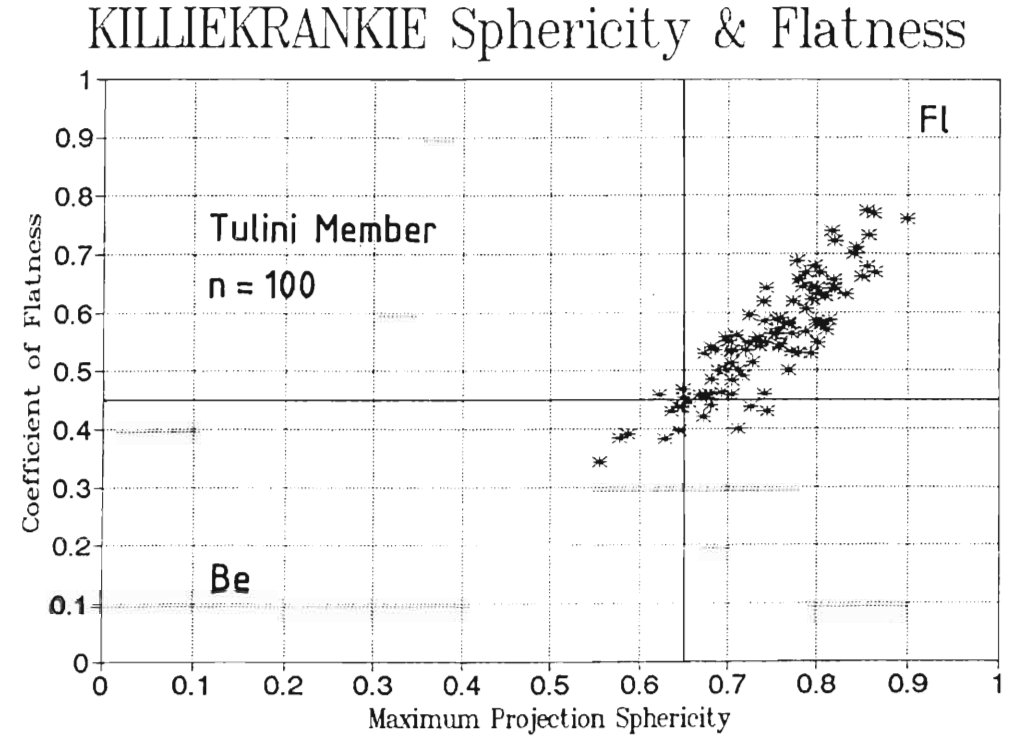
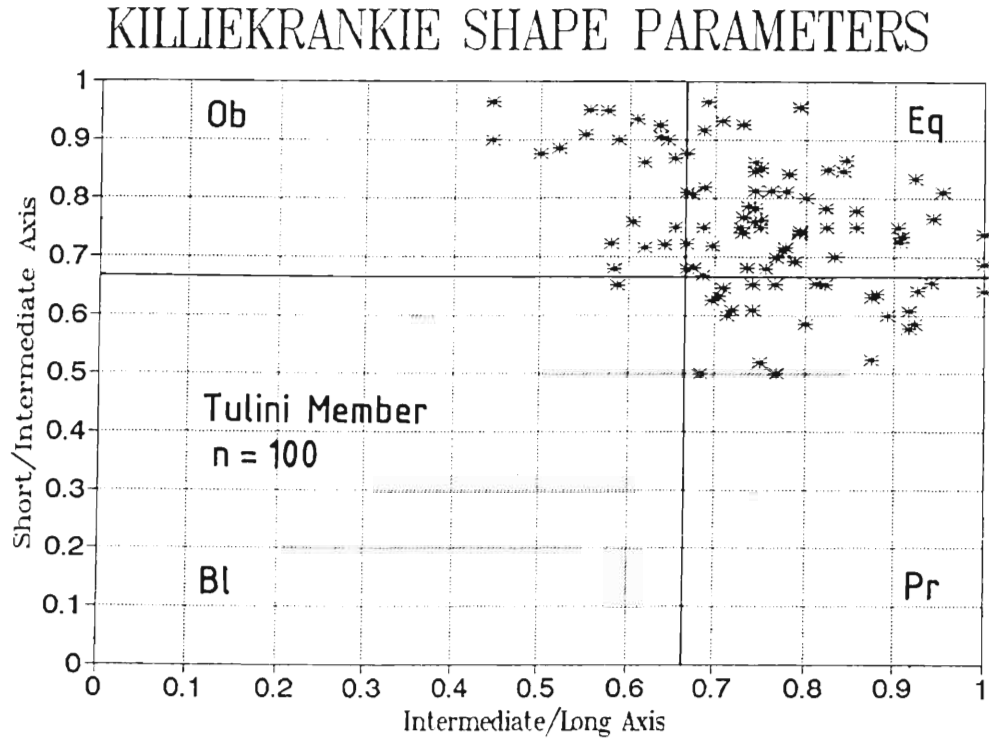


Fig. App-5.1 Shape parameter and flatness vs sphericity - Honeygrove

Sampling Locality C



Ob = Oblate Eq = Equant Bl = Bladed Pr = Prolate
 Fl = Fluvial Be = Beach n = number of clasts counted

Fig. App-5.2 Shape parameter and flatness vs sphericity - Killiekrankie

Sampling Locality D

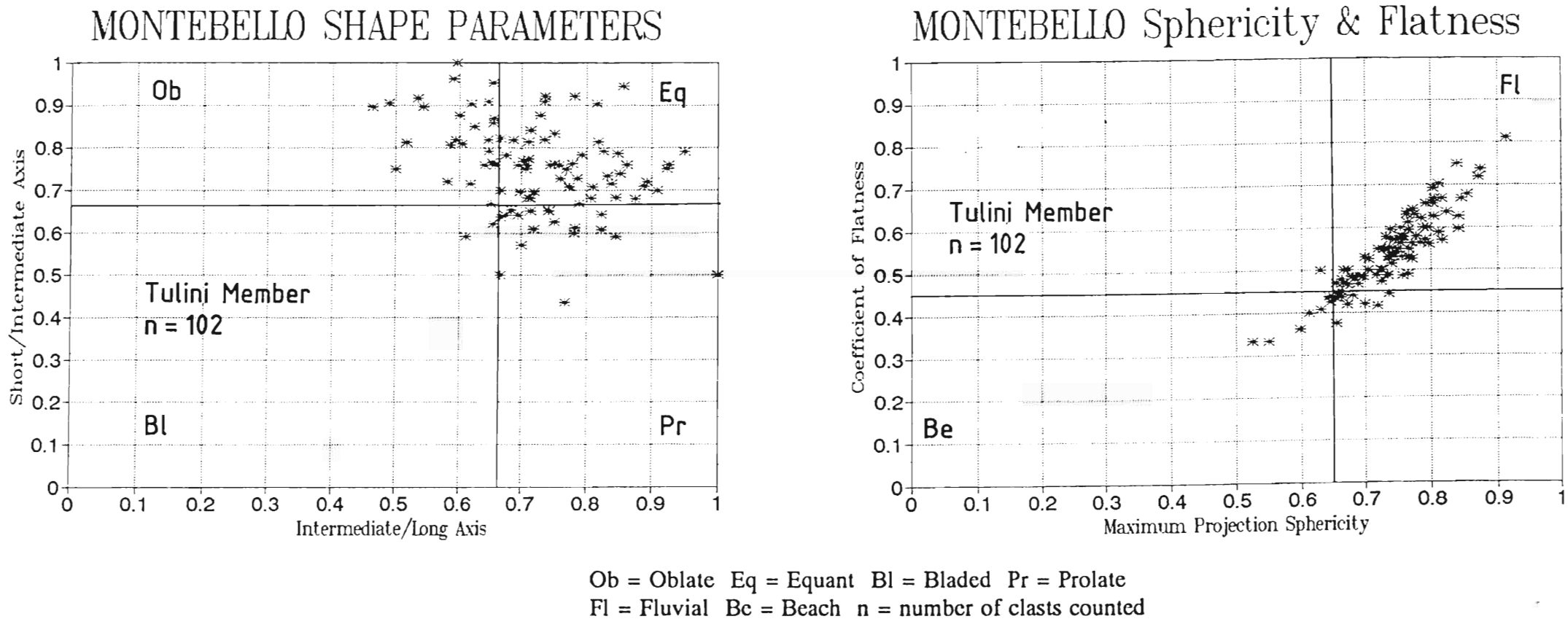
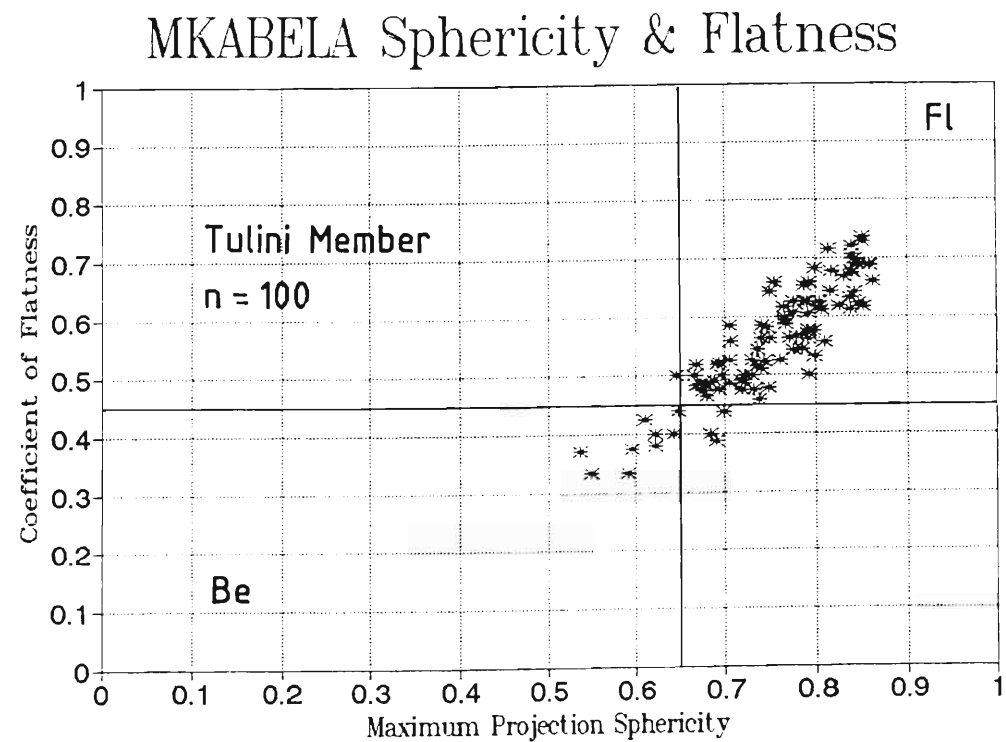
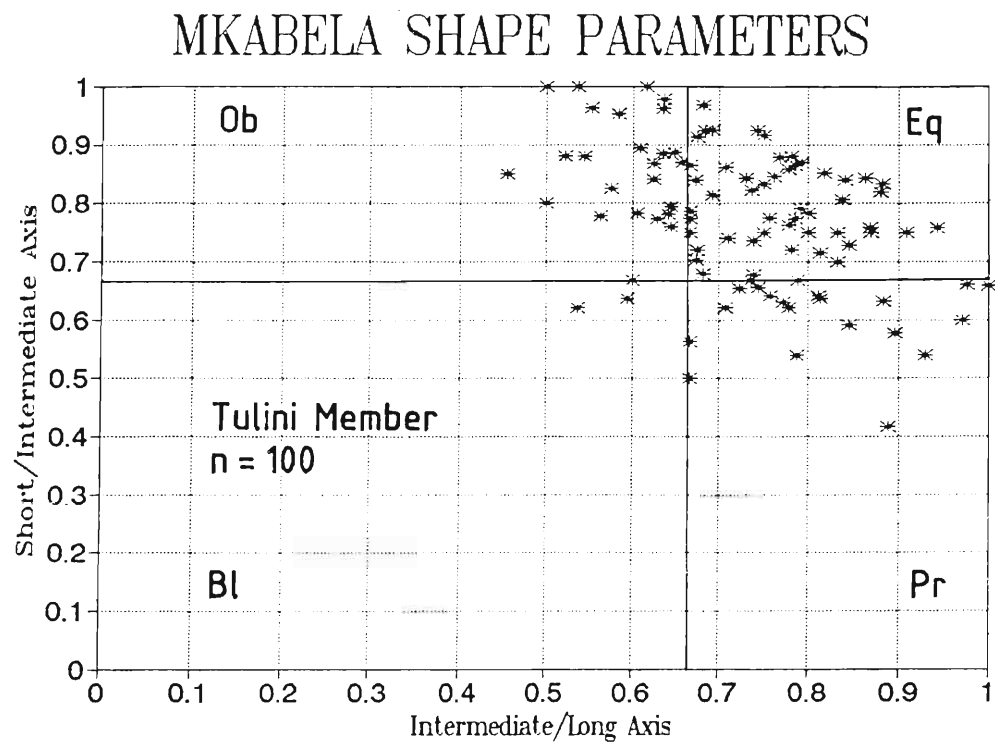


Fig. App-5.3 Shape parameter and flatness vs sphericity - Montebello

Sampling Locality E

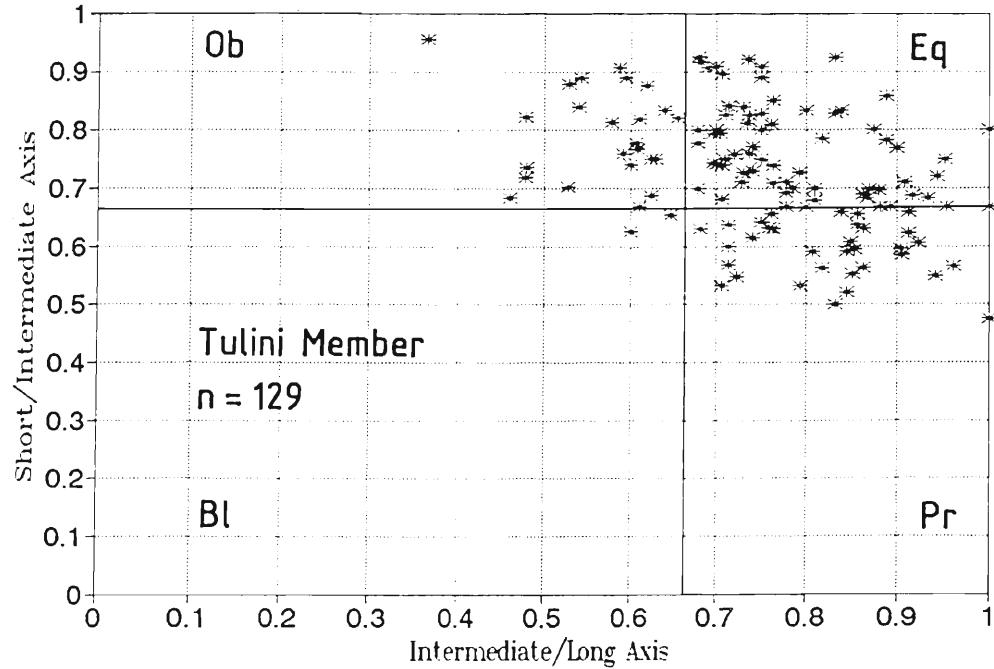


Ob = Oblate Eq = Equant Bl = Bladed Pr = Prolate
 Fl = Fluvial Be = Beach n = number of clasts counted

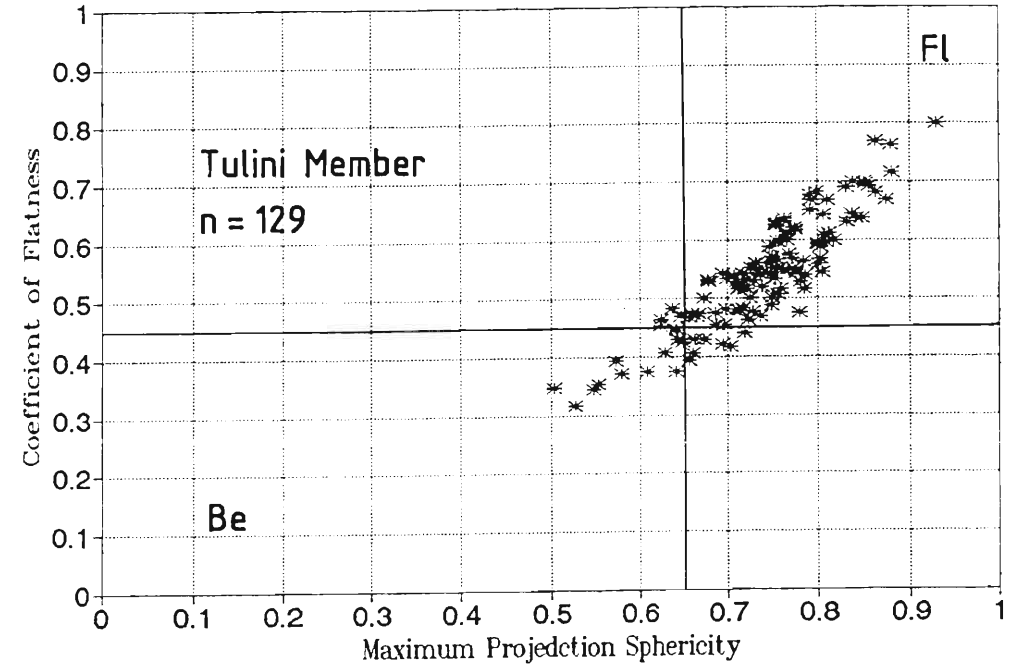
Fig. App-5.4 Shape parameter and flatness vs sphericity - Mkabela

Sampling Locality F

BAVIAANSKRANS SHAPE PARAMETERS



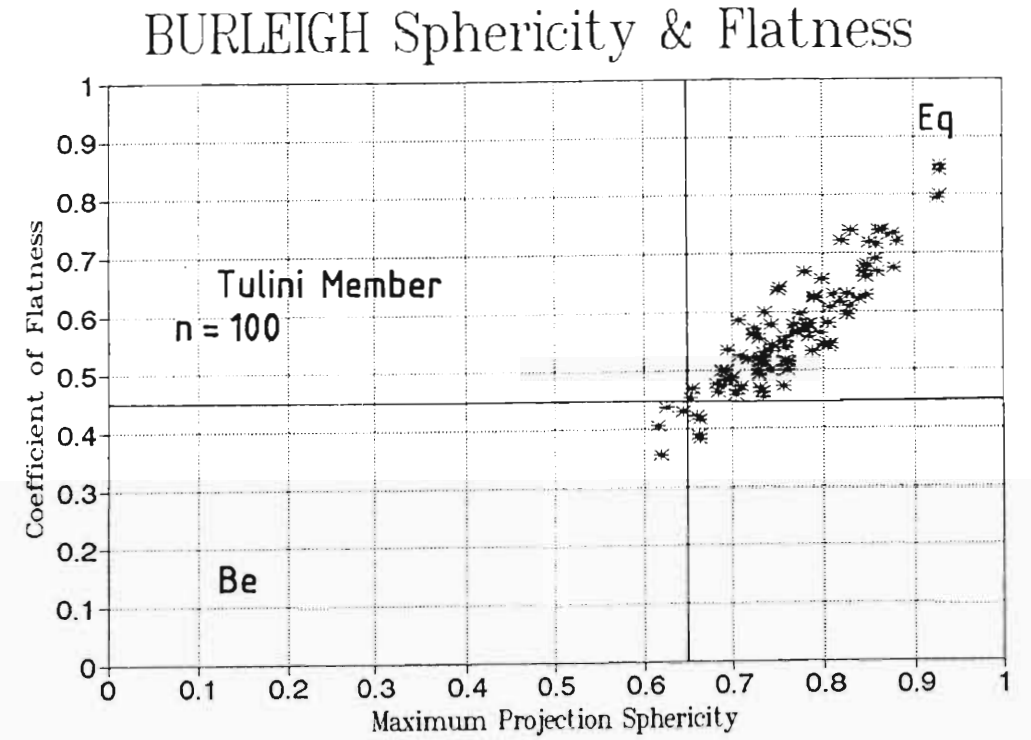
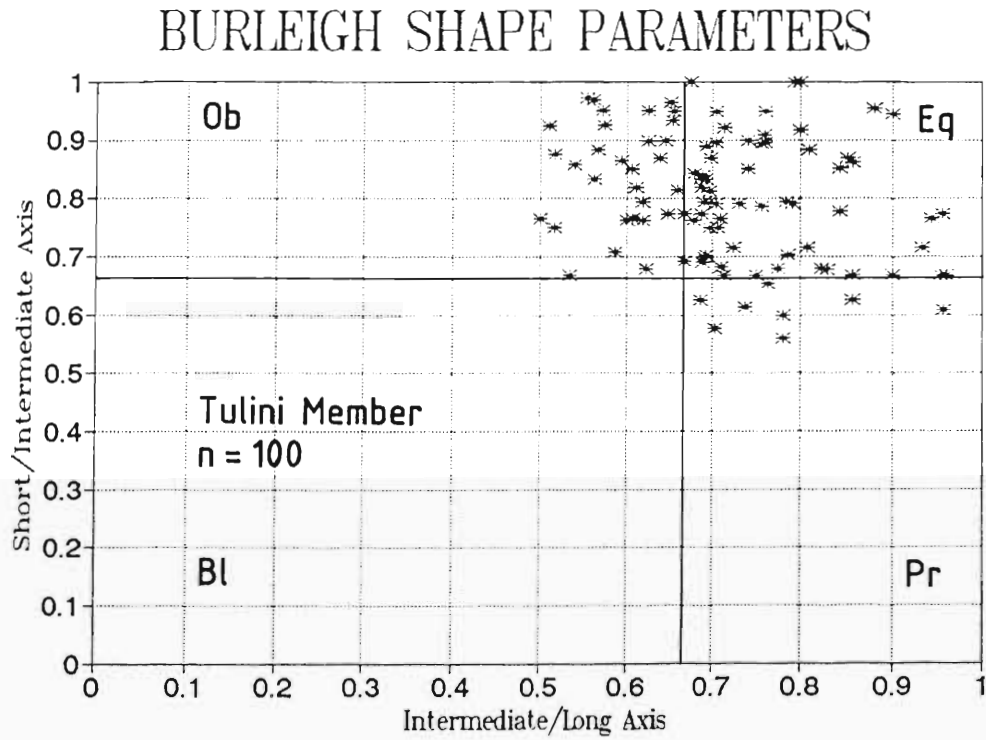
BAVIAANSKRANS Sphericity & Flatness



Ob = Oblate Eq = Equant Bl = Bladed Pr = Prolate
 Fl = Fluvial Bc = Beach n = number of clasts counted

Fig. App-5.5 Shape parameter and flatness vs sphericity - Baviaanskrans

Sampling Locality G

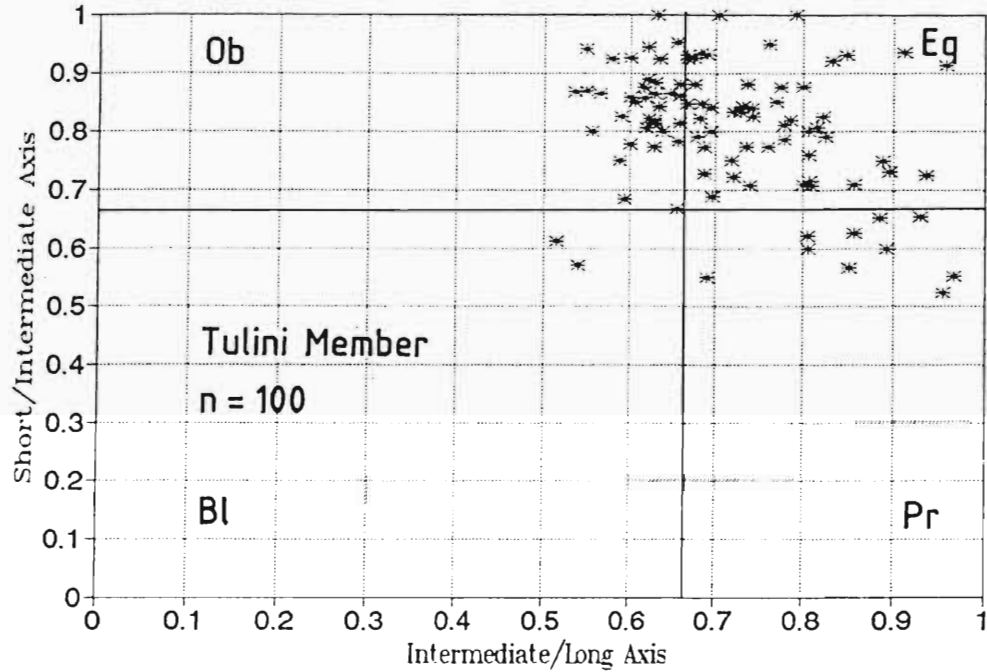


Ob = Oblate Eq = Equant Bl = Bladed Pr = Prolate
 Fl = Fluvial Be = Beach n = number of clasts counted

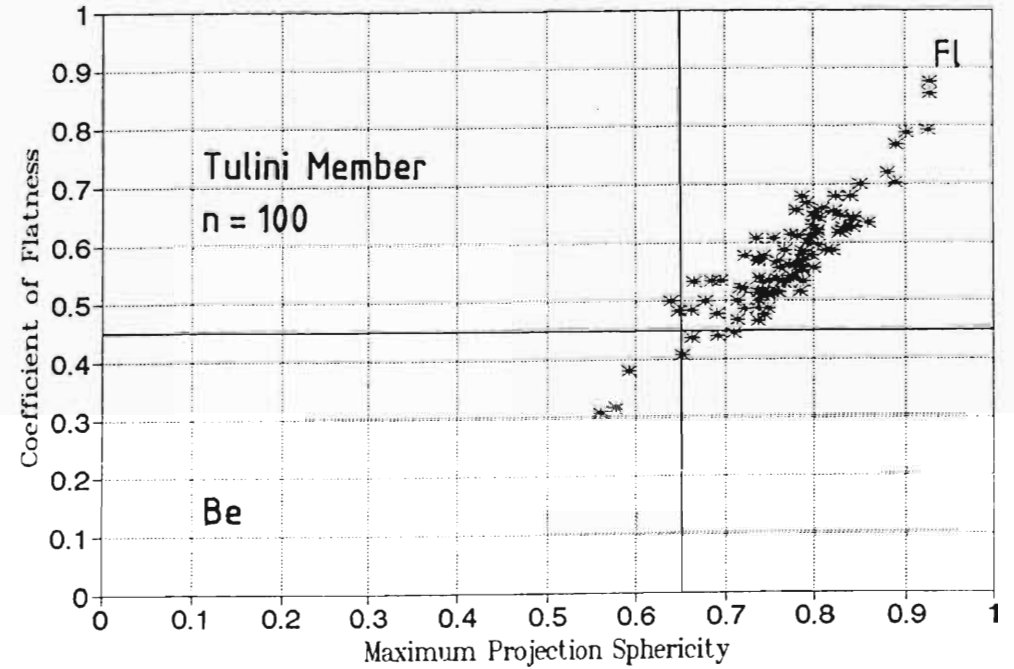
Fig. App-5.6 Shape parameter and flatness vs sphericity - Burleigh

Sampling Locality H

BULWANA SHAPE PARAMETERS



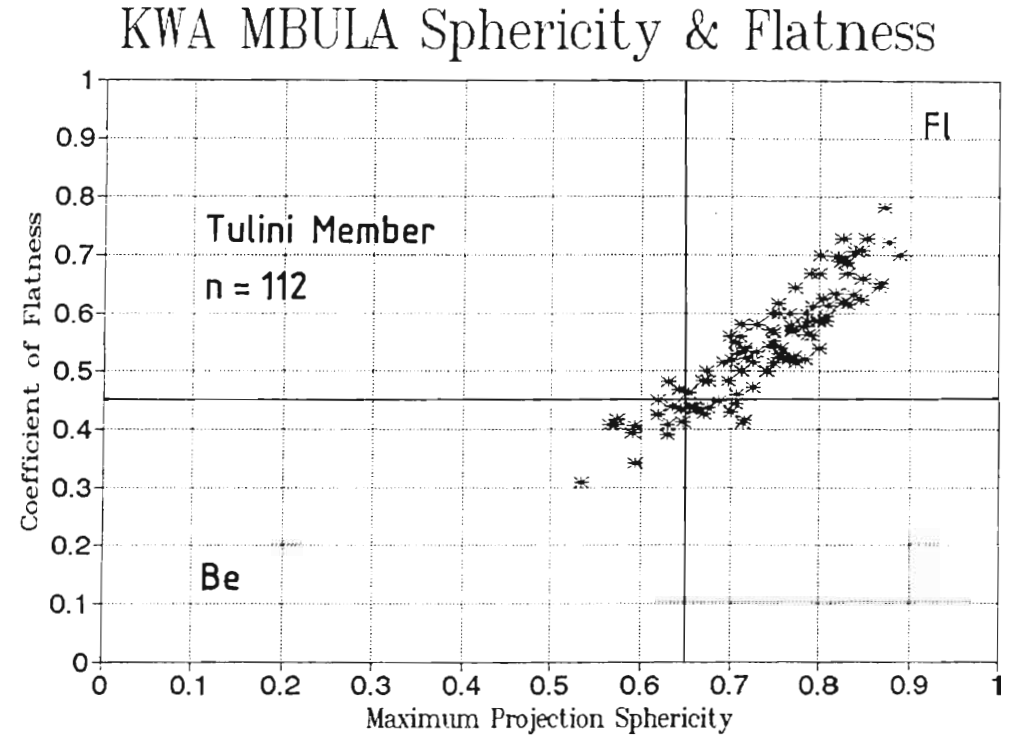
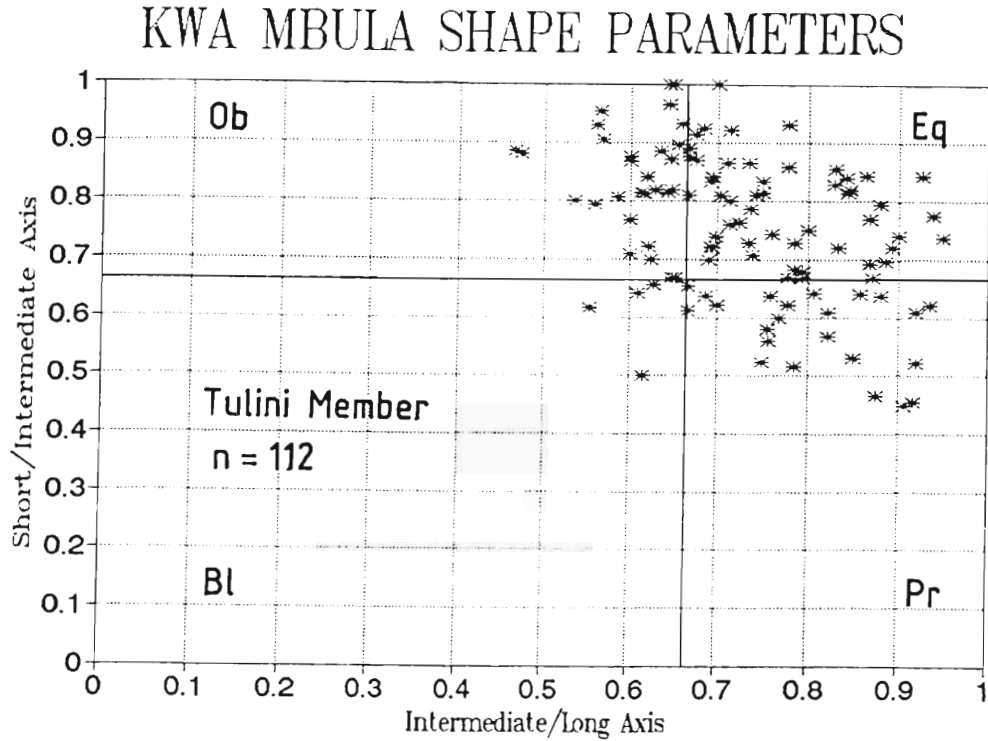
BULWANA Sphericity & Flatness



Ob = Oblate Eg = Equant Bl = Bladed Pr = Prolate
 Fl = Fluvial Be = Beach n = number of clasts counted

Fig. App-5.7 Shape parameter and flatness vs sphericity - Bulwana

Sampling Locality I



Ob = Oblate Eq = Equant Bl = Bladed Pr = Prolate
 FI = Fluvial Bc = Beach n = number of clasts counted

Fig. App-5.8 Shape parameter and flatness vs sphericity - Kwa Mbula

Sampling Locality J

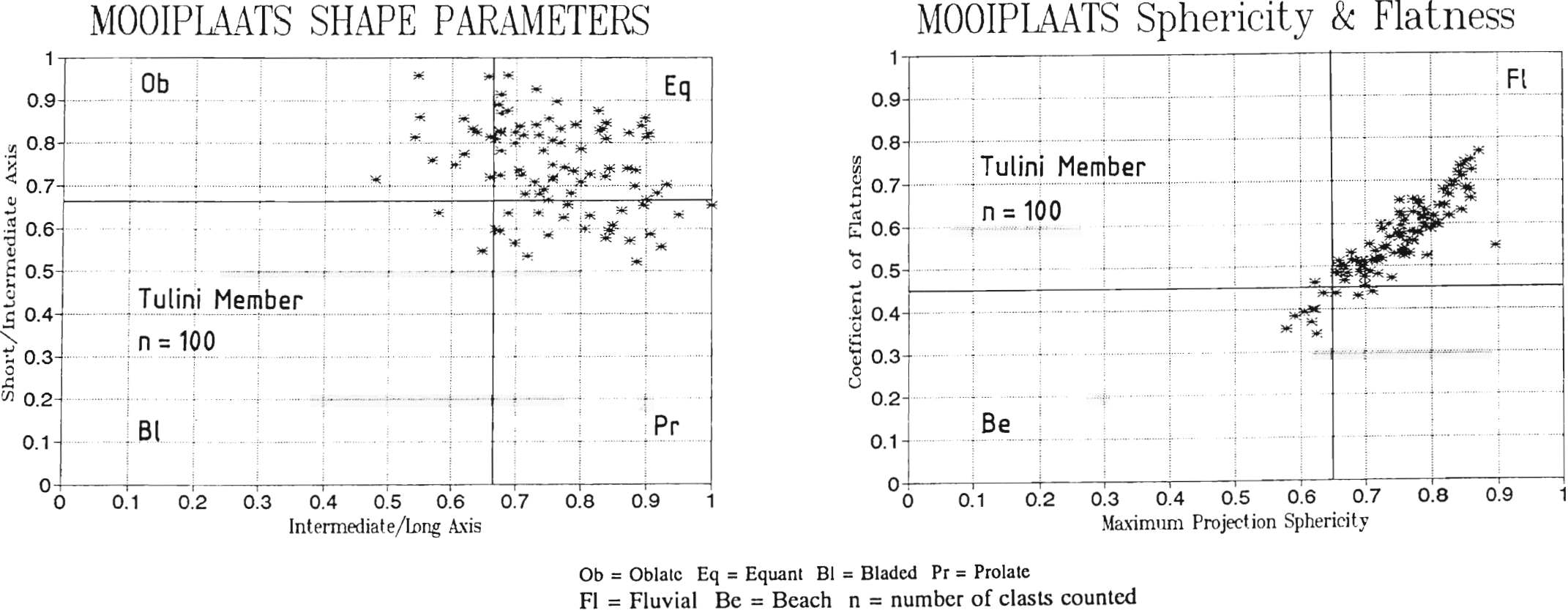


Fig. App-5.9 Shape parameter and flatness vs sphericity - Mooiplaats

Sampling Locality K

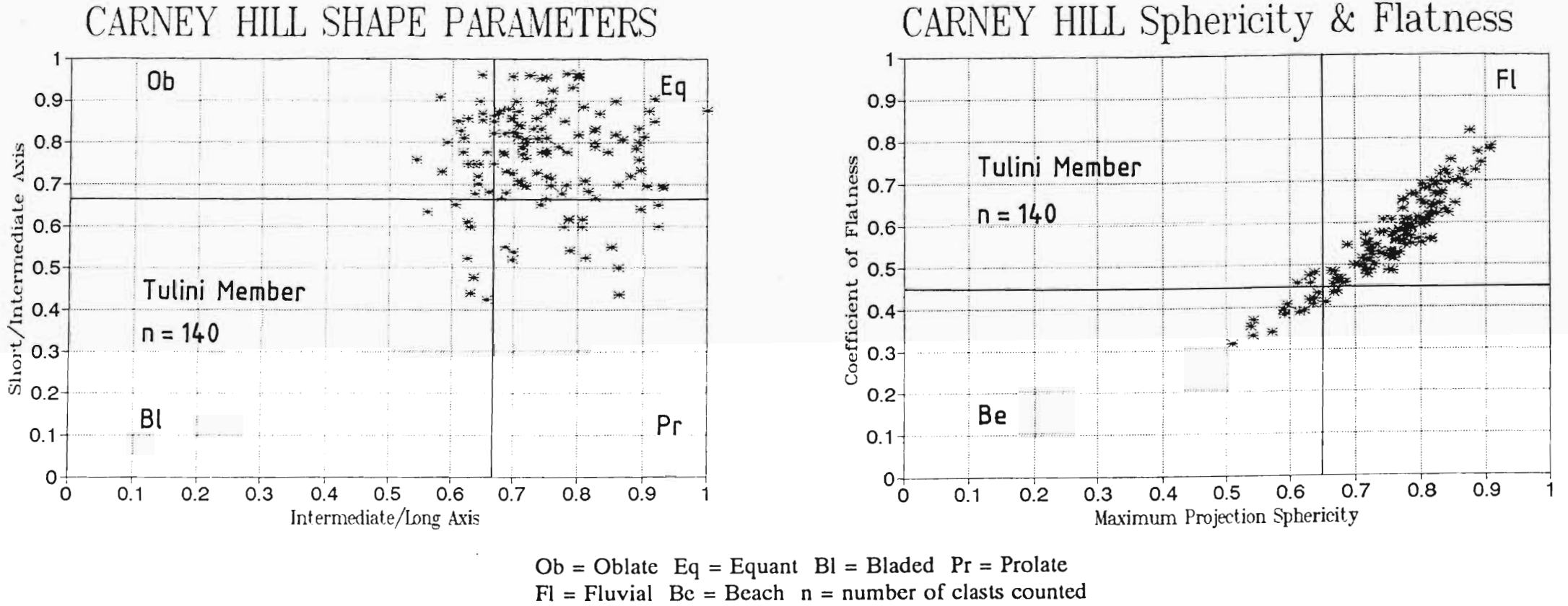


Fig. App-5.10 Shape parameter and flatness vs sphericity - Carney Hill

Sampling Locality L

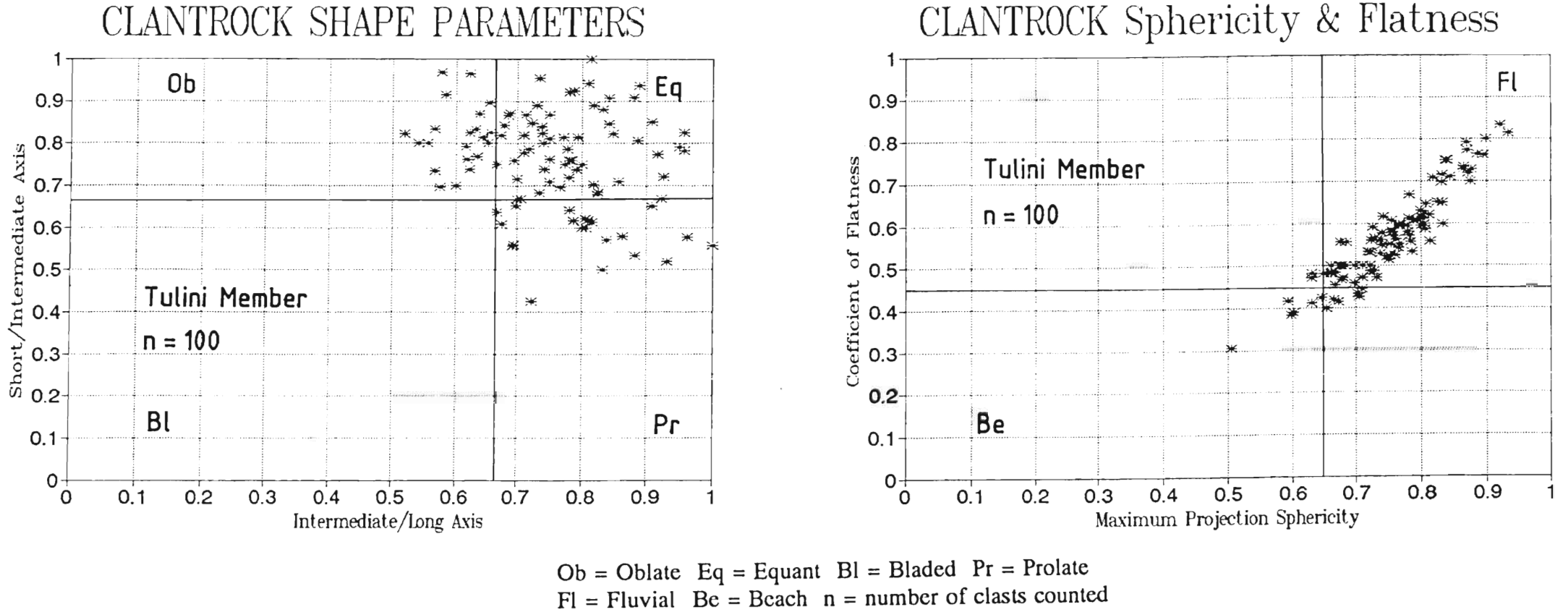


Fig. App-5.11 Shape parameter and flatness vs sphericity - Clantrock

Sampling Locality M

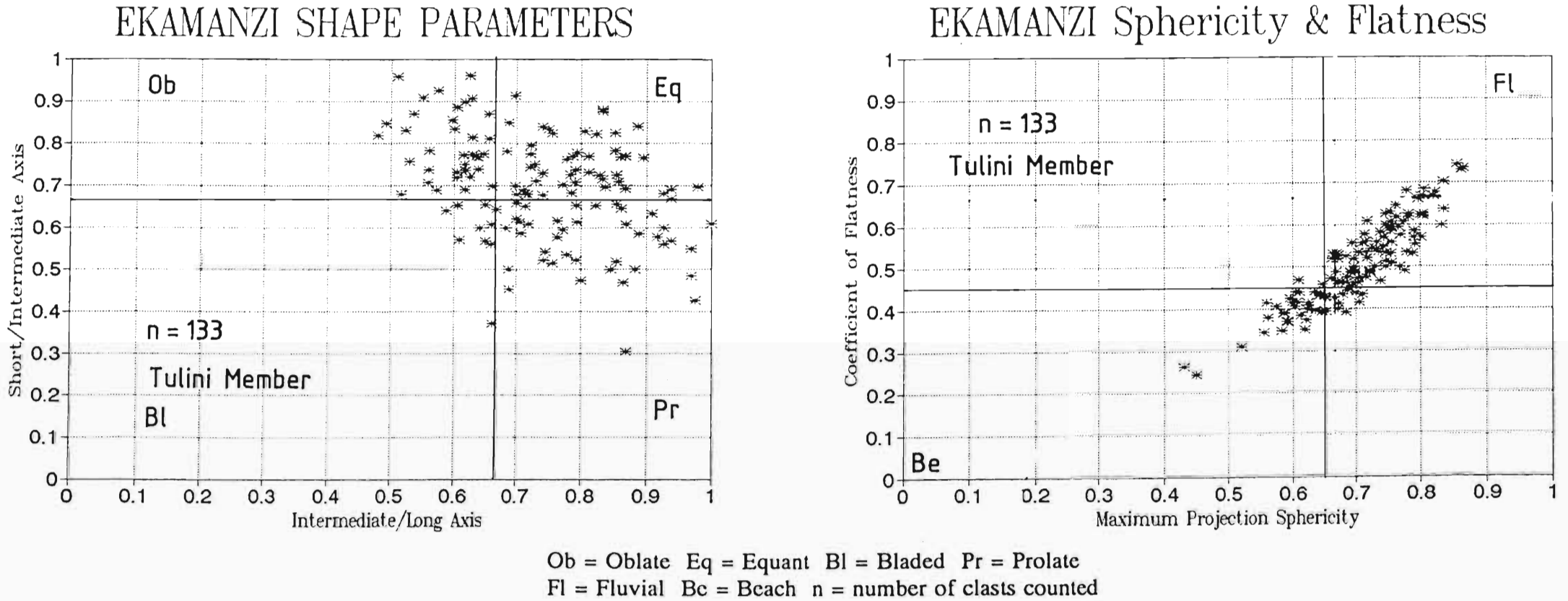


Fig. App-5.12 Shape parameter and flatness vs sphericity - Ekamanzi

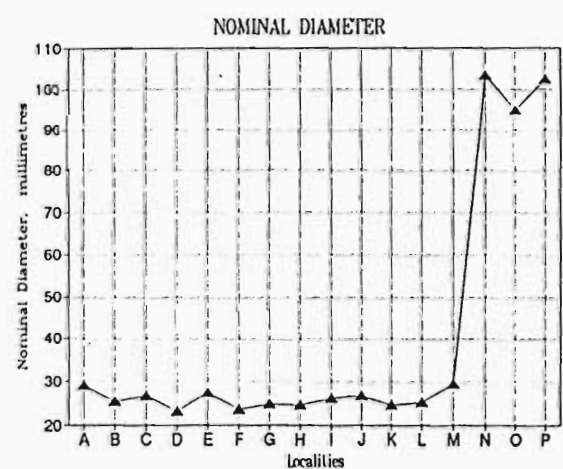
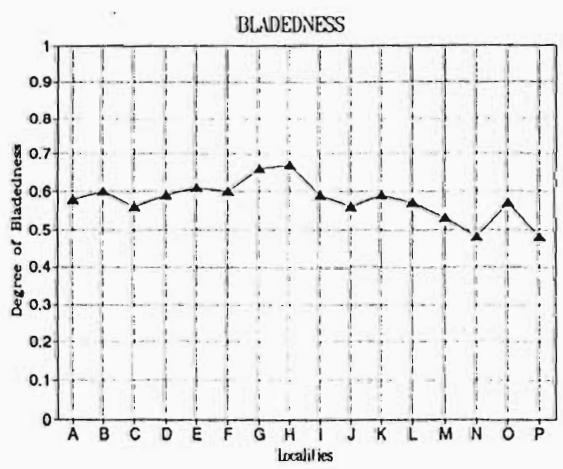
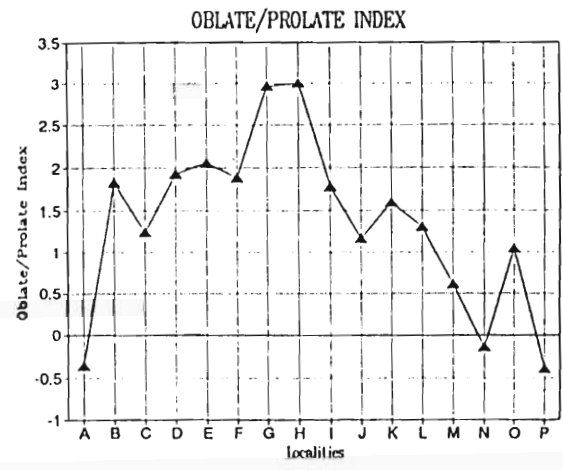
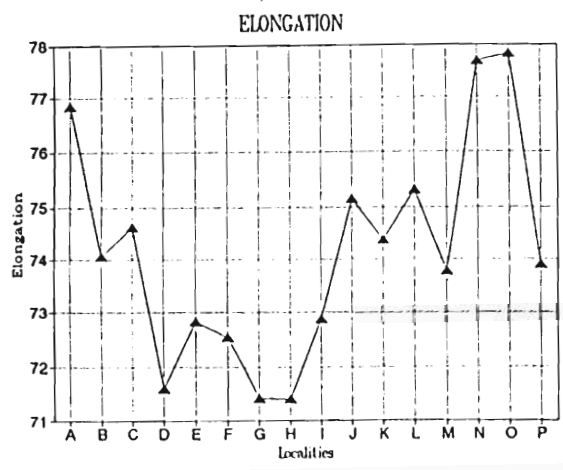
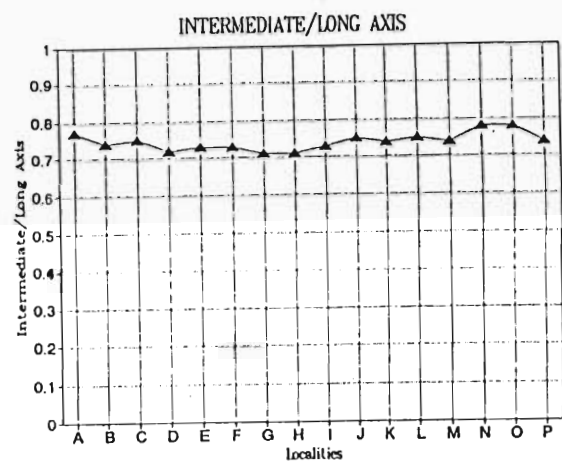
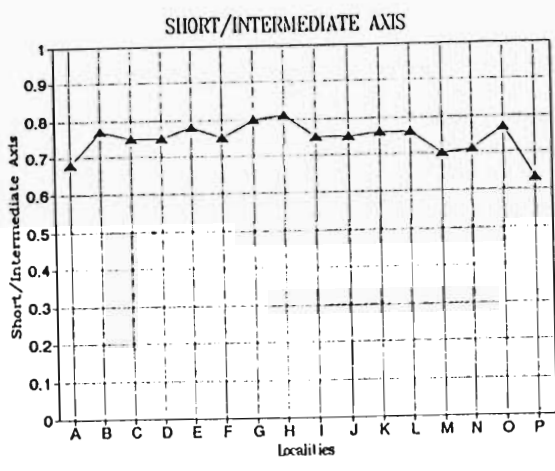
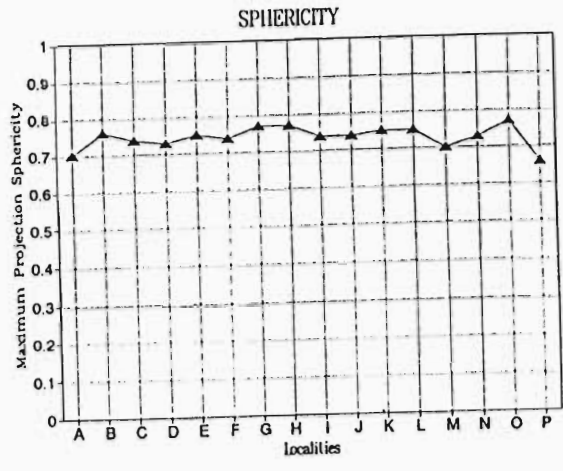
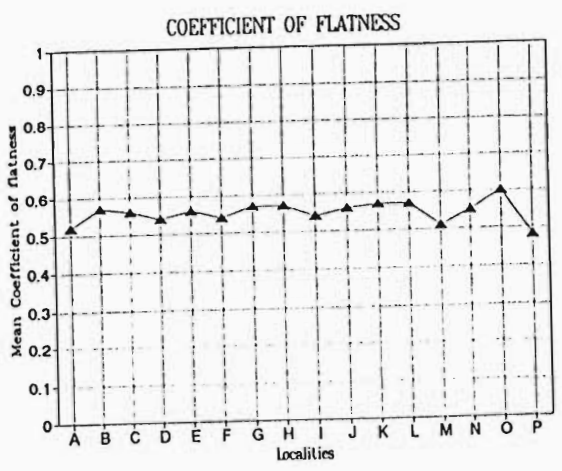


Fig. 3.57 Graphs of clast-shape statistics

Table App-5.1: Summary of clast-shape statistics of Ulundi, Tulini and Westville Members

SITE NAME	Stratigraphic Unit	Sample Size	Flatness Coeff.	Bladedness	Oblate/Prolate Index	Max.Proj. Sphericity	Elongation	Nominal Diam. mm	Interm/Long Axis	Short/Interm Axis	SYMBOL		
											LATITUDE	LONGITUDE	
Mntamnto	Westville	202	0.52	0.58	-0.36	0.7	76.84	28.94	0.77	0.68	A	29°52'40"	30°37'35"
Honeygrove	Tulini	100	0.57	0.6	1.83	0.76	74.06	25.23	0.74	0.77	B	29°25'56"	30°45'08"
Killiekrankie	Tulini	100	0.56	0.56	1.25	0.74	74.64	26.48	0.75	0.75	C	29°26'58"	30°44'37"
Montebello	Tulini	102	0.54	0.59	1.93	0.73	71.62	23.18	0.72	0.75	D	29°27'12"	30°49'38"
Mkabela	Tulini	100	0.56	0.61	2.06	0.75	72.82	27.3	0.73	0.78	E	29°24'28"	30°38'25"
Baviaanskrans	Tulini	129	0.54	0.6	1.88	0.74	72.54	23.38	0.73	0.75	F	29°09'38"	30°42'07"
Burleigh	Tulini	100	0.57	0.66	2.96	0.77	71.44	24.83	0.71	0.8	G	29°09'00"	30°40'30"
Bulwana	Tulini	100	0.57	0.67	3	0.77	71.42	24.55	0.71	0.81	H	29°12'28"	30°52'00"
Kwa Mbula	Tulini	112	0.54	0.59	1.78	0.74	72.87	25.99	0.73	0.75	I	29°10'47"	30°46'01"
Mooiplaats	Tulini	100	0.56	0.56	1.17	0.74	75.15	26.68	0.75	0.75	J	29°21'05"	30°35'22"
Carney Hill	Tulini	140	0.57	0.59	1.6	0.75	74.39	24.5	0.74	0.76	K	29°13'12"	30°45'02"
Clantrook	Tulini	100	0.57	0.57	1.31	0.75	75.31	25.09	0.75	0.76	L	29°25'09"	30°47'17"
Ekamanzi	Tulini	133	0.51	0.53	0.61	0.7	73.78	29.41	0.74	0.7	M	29°16'48"	30°37'45"
Dolwana	Ulundi	50	0.55	0.48	-0.14	0.73	77.69	103.37	0.78	0.71	N	28°42'04"	30°56'52"
Ulundi	Ulundi	100	0.6	0.57	1.05	0.77	77.84	94.94	0.78	0.77	O	28°19'27"	31°23'26"
Nsuze	Ulundi	40	0.48	0.48	-0.39	0.66	73.91	102.47	0.74	0.63	P	31°38'45"	30°57'45"

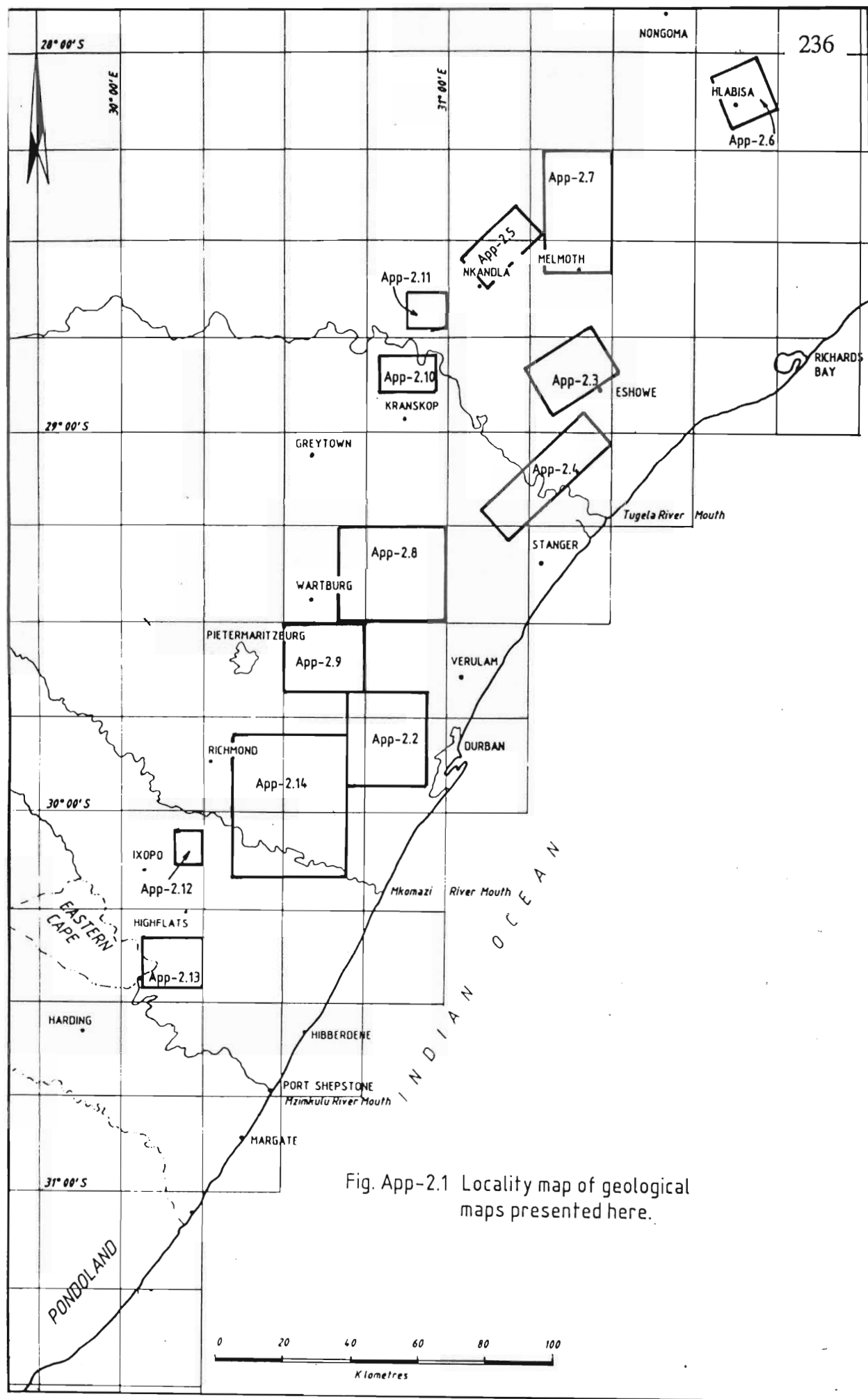


Fig. App-2.1 Locality map of geological maps presented here.

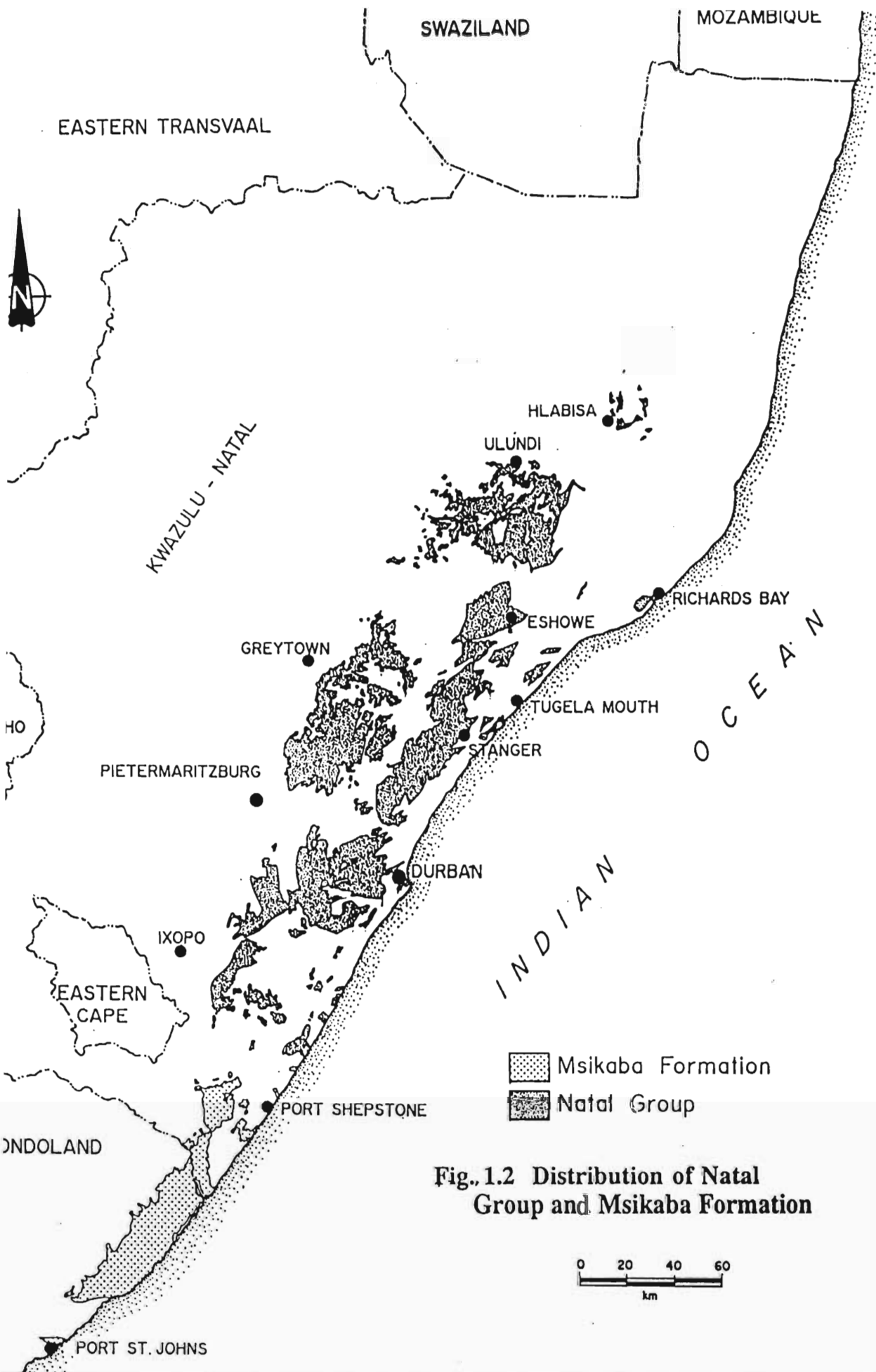


Fig. 1.2 Distribution of Natal Group and Msikaba Formation

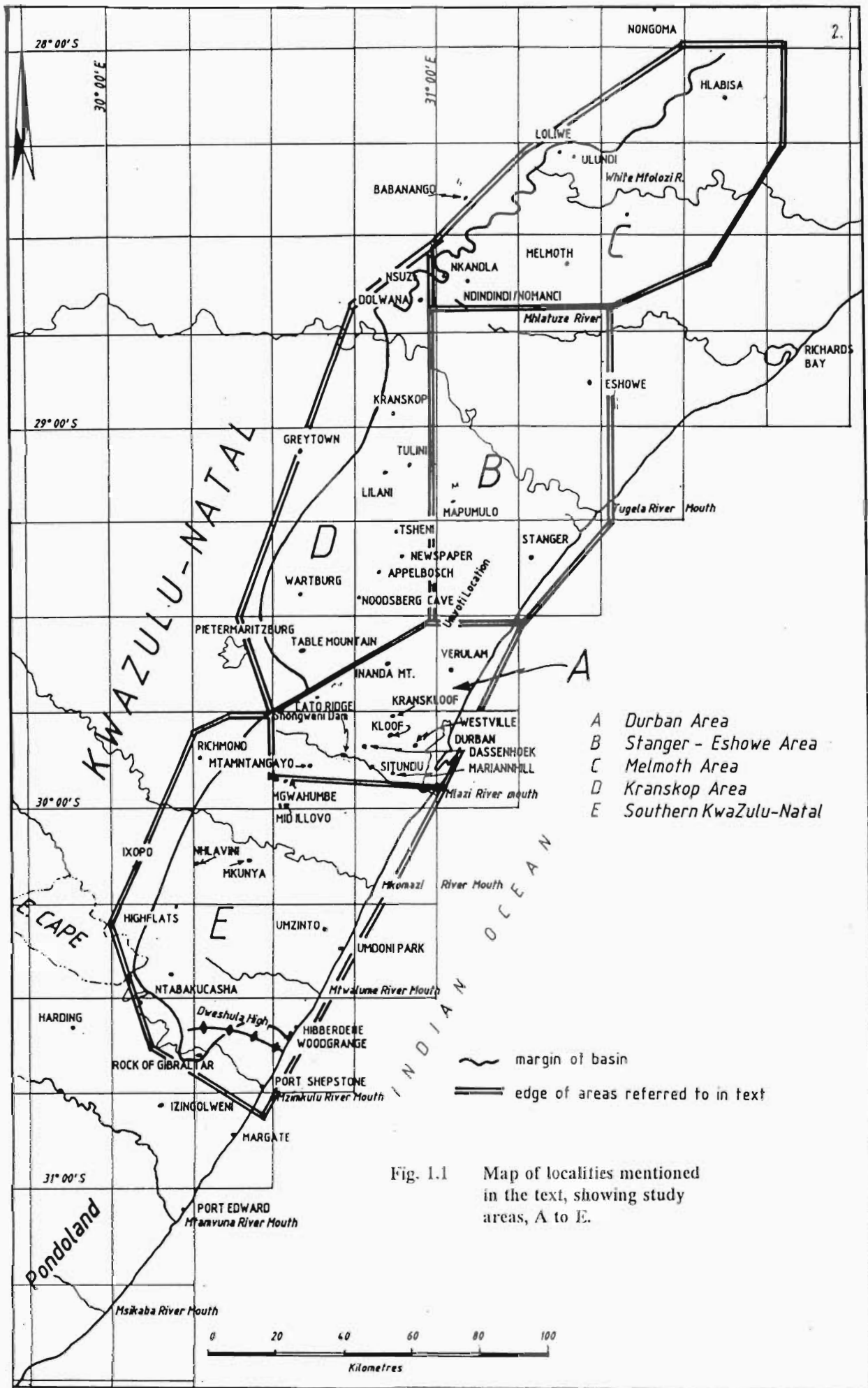


Fig. 1.1 Map of localities mentioned in the text, showing study areas, A to E.