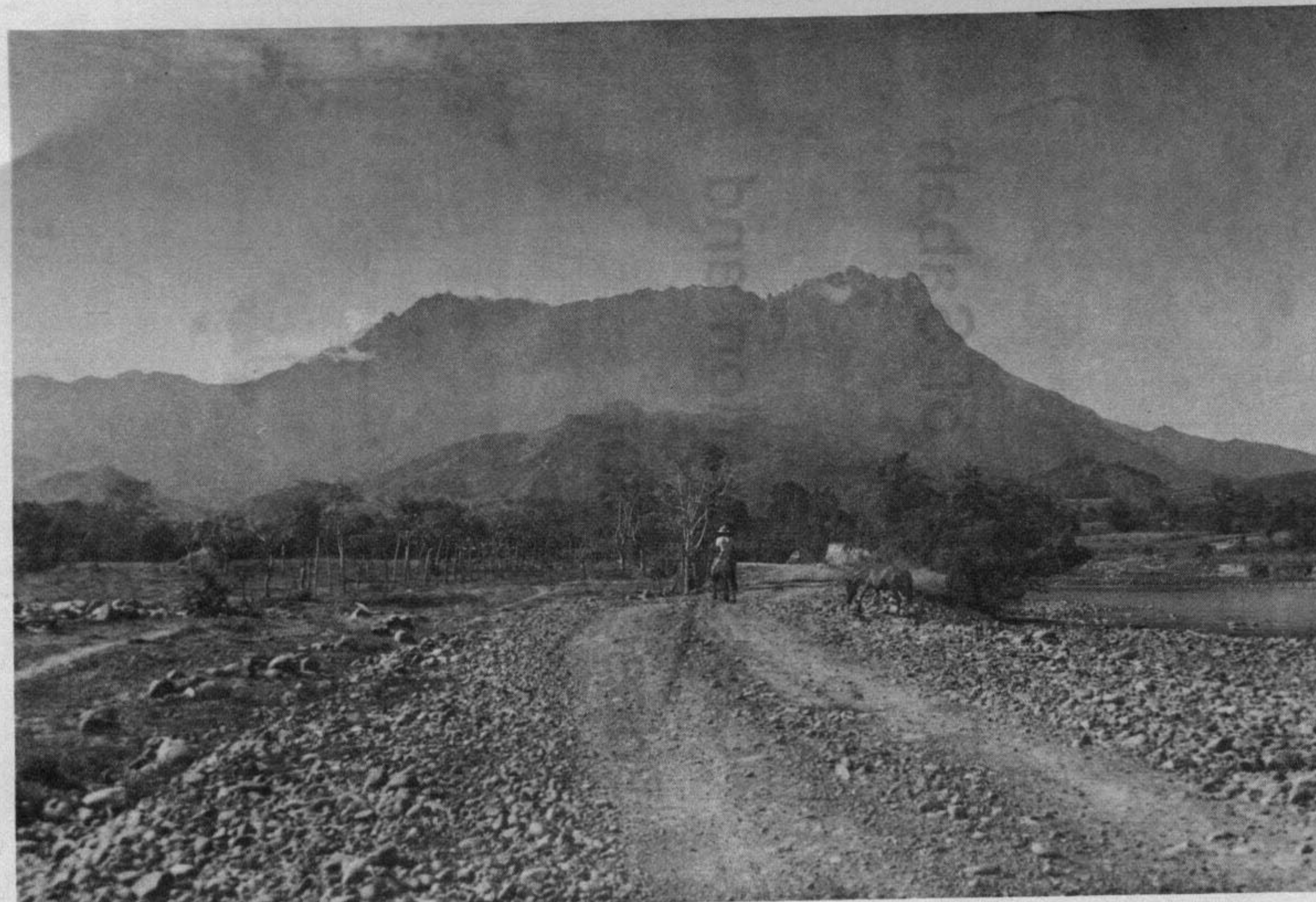
Land Resource Study

20 The Soils of Sabah Volume 1 Classification and description

Land Resources Division, Ministry of Overseas Development,
Tolworth Tower, Surbiton, Surrey, England KT6 7DY

B DA

The soils of Sabah
Volume 1
Classification and description



Gunong Kinabalu from Kota Belud

Land Resources Division

The soils of Sabah

Volume 1

Classification and description (with an introduction to Volumes 1-5)

B D Acres, R P Bower, P A Burrough, C J Folland, M S Kalsi, P Thomas and P S Wright

Land Resource Study 20

Land Resources Division, Ministry of Overseas Development
Tolworth Tower, Surbiton, Surrey, England KT6 7DY
1975

THE LAND RESOURCES DIVISION

The Land Resources Division of the Ministry of Overseas Development assists developing countries in mapping, investigating and assessing land resources, and makes recommendations on the use of these resources for the development of agriculture, livestock husbandry and forestry; it also gives advice on related subjects to overseas governments and organisations, makes scientific personnel available for appointment abroad and provides lectures and training courses in the basic techniques of resource appraisal.

The Division works in close co-operation with government departments, research institutes, universities and international organisations concerned with land resources assessment and development planning.

List of volumes

Volume 1	Classification and description (with an introduction to Volumes 1-5). B D Acres, R P Bower, P A Burrough, C J Folland, M S Kalsi, P Thomas and P S Wright. Volume 1 is accompanied by maps of the soils of Sabah.
Volume 2	Sandakan and Kinabatangan Districts. B D Acres and C J Folland.
Volume 3	Western Parts of Tawau and Lahad Datu Districts. P S Wright.
Volume 4	South-Western Districts. R P Bower, P A Burrough, M S Kalsi and P Thomas.
Volume 5	References and appendixes. B D Acres, R P Bower, P A Burrough, C J Folland, M S Kalsi, P Thomas and P S Wright.

Contents

LIST OF FIGURES xi

LIST OF PLATES xiii

LIST OF TEXT MAPS xiii

LIST OF SEPARATE MAPS xiii

Introduction to volumes 1-5

Preface 1

Acknowledgements 1

Abstract 2

Résumé 2

List of contributors 3

History of the study 3

Soil survey methods 7

Volume 1

PART 1. INTRODUCTION 9

Acknowledgements 9

Abstract 9

Résumé 9

PART 2. GEOGRAPHICAL BACKGROUND 11

Settlement and communications 11

Climate 11

Physiography 12

Geology 12

Forestry 17

Agriculture 17

The economy 17

PART 3. SOIL FORMATION 19

PART 4. SOIL CLASSIFICATION 23

Introduction to the soil units 23

Histosols 35
General description 35
Dystric Histosols 35
Klias Family 35
Kaintano Family 37
Arang Family 37
Eutric Histosols 37
Mengalum Family 37

Lithosols 37

Fluvisols 38
General description 38
Thionic Fluvisols 38
Weston Family 38
Kalibong Family 41
Calcaric Fluvisols 41
Nunuyan Family 41
Dystric Fluvisols 41
Tenghilan Family 41
Eutric Fluvisols 41
Pegalan Family 41

Gleysols 42
General description 42
Humic Gleysols 42
Berhala Family 42
Guan Family 42
Kidukarak Family 46
Wullersdorf Family 46
Thionic-humic Gleysols 46
Bergosong Family 46
Calcaric Gleysols 46
Lari Family 46
Dystric Gleysols 46
Koyah Family 47
Thionic-dystric Gleysols 47
Metah Family 47

Eutric Gleysols 47
Bangawat Family 47
Rasang Family 47
Thionic-eutric Gleysols 50
Libur Family 50

Regosols 50
General description 50
Calcaric Regosols 50
Usukan Family 50
Dystric Regosols 51
Tamanong Family 51
Eutric Regosols 51
Tanjong Lita Family 51
Tanjong Family 51

Rankers 51
General description 51
Kinabalu Family 51

Podzols 53
General description 53
Placic Podzols 54
Mesilau Family 54
Gleyic Podzols 54
Baiayo Family 54
Pa Sia Family 54
Humic Podzols 57
Karamatoi Family 57
Orthic Podzols 57
Silimpopon Family 59
Sibuga Family 59

Ferralsols 59
General description 59
Rhodic Ferralsols 60
Apas Family 60
Pinianakan Family 60
Xanthic Ferralsols 60
Tungau Family 60
Jarangan Family 62
Orthic Ferralsols 62
Nobusu Family 62
Ambun Family 62
Table Family 62
Benuou Family 63

Rendzinas 63
General description 63
Loc Sambuang Family 63

Acrisols 63
General description 63
Gleyic Acrisols 66
Inanam Family 66
Koung Family 66
Gunong Alab Family 66
Masaum Family 70
Humic Acrisols 70
Kiau Family 70

Ferric Acrisols 70
Lumisir Family 70
Beruang Family 70
Sipit Family 70
Batang Family 74
Orthic Acrisols 74
Katai Family 74
Paliu Family 74
Kinabutan Family 75
Dagat Family 75
Mensuli Family 75
Kumansi, Tanjong Lipat and Kapilit Families 75

Luvisols 80
General description 80
Gleyic Luvisols 80
Nangoh Family 82
Lungpatau Family 82
Buran Family 82
Lunparai Family 82
Calcic Luvisols 83
Semporna Family 83
Ferric Luvisols 83
Pantagaluang Family 83
Besar Family 84
Lumerau Family 84
Chromic Luvisols 84
Mangkap Family 84
Terang Family 88
Sabor Family 88
Malawali Family 88
Beeston Family 88
Libong Family 89
Tegupi Family 89
Orthic Luvisols 89
Numatoi Family 89
Darau Family 89
Tingkayu Family 91
Kobovan Family 91
Talid Family 91
Lumpongon Family 92

Cambisols 92
General description 92
Gleyic Cambisols 92
Sinsulod Family 95
Luba Family 95
Calcic Cambisols 95
Madai Family 95
Humic Cambisols 95
Mantaki Family 95
Chromic Cambisols 96
Mangkawagu Family 96
Silad Family 96
Kawa Family 96
Sadok Family 96
Juak Family 99
Luasong Family 99
Dystric Cambisols 99
Kelawat Family 99
Meliau Family 99

Nerelud Family 99
Tenggara Family 100
Durikong Family 100
Laab Family 100
Antulai Family 100
Eutric Cambisols 100
Bulanat Family 100
Binuang Family 102
Bombalai Family 102
Quarry Family 102
Hatton Family 102

Arenosols 102
General description 102
Albic Arenosols 103
Serai Family 103
Cambic Arenosols 103
Pisau Family 103
Kabili Family 103
Pangarangan Family 103

PART 5. THE SOIL ASSOCIATIONS 107

Introduction 107

Soil associations on alluvium 107
1. Tidal swamps and beaches 107
2. Floodplains 113
3. Valley floors and associated terraces 115
4. Terraces 117
5. Plateaus 119

Soil associations on mudstone/sandstone 120
1. Mudstone and minor sandstone 120
2. Sandstone and mudstone 121
3. Mudstone, sandstone and miscellaneous rocks 124

Soil associations on limestone 127

Soil associations on acid igneous rocks 128

Soil associations on intermediate igneous rocks 128

Soil associations on basic igneous rocks 129

Soil associations on ultrabasic igneous rocks 131

PUBLICATIONS OF THE LAND RESOURCES DIVISION 133

LIST OF FIGURES

1-1 to 1-30 Criteria for subdivision of soil units and subdivisions described

1-1 Histosols 36

1-2 Thionic and Calcaric Fluvisols 39

1-3	Dystric and Eutric Fluvisols	40
1-4	Humic Gleysols on alluvium	44
1-5	Humic Gleysols on sandstone and acid igneous rocks	45
1-6	Dystric Gleysols on alluvium	48
1-7	Eutric Gleysols on alluvium	49
1-8	Calcaric, Dystric and Eutric Regosols	52
1-9	Gleyic Podzols on alluvium	55
1-10	Gleyic Podzols on sandstone and mudstone	56
1-11	Humic and Orthic Podzols	58
1-12	Ferralsols	61
1-13	Gleyic Acrisols on alluvium	67
1-14	Gleyic Acrisols on mudstone and sandstone	68
1-15	Ferric Acrisols on alluvium	69
1-16	Ferric Acrisols on mudstone and sandstone	72
1-17	Orthic Acrisols on alluvium	73
1-18	Orthic Acrisols on basic and intermediate rocks and tuffaceous rocks	76
1-19	Orthic Acrisols on mudstone	77
1-20	Orthic Acrisols on sandstone and mudstone	78
1-21	Gleyic Luvisols	83
1-22	Ferric Luvisols	85
1-23	Chromic Luvisols on alluvium	86
1-24	Chromic Luvisols on ultrabasic and basic igneous rocks, limestone and tuffaceous rocks	87
1-25	Orthic Luvisols	90
1-26	Gleyic Cambisols	94
1-27	Chromic Cambisols	97
1-28	Dystric Cambisols	98
1-29	Eutric Cambisols	101
1-30	Arenosols	104

LIST OF PLATES

Frontispiece	Gunong Kinabalu from Kota Belud	
1-1	Gleyic Podzol (Pa Sia Family)	26
1-2	Orthic Podzol (Silimpopon Family)	27
1-3	Dystric Cambisol (Kalawat Family)	27
1-4	Orthic Acrisol (Kumansi Family)	28
1-5	Clay cutans in argillic horizon of Orthic Acrisol (Paliu Family)	28
1-6	Orthic Acrisol (Tanjong Lipat Family)	29
1-7	Orthic Acrisol (Tanjong Lipat Family)	29
1-8	Orthic Acrisol (Kumansi Family)	29
1-9	Orthic Acrisol (Kumansi Family)	29
1-10	Gleyic Acrisol (Inanam Family)	31
1-11	Gleyic Acrisol (Gunong Alab Family)	31
1-12	Orthic Acrisol (Paliu Family)	31
1-13	Humic Gleysol (Guan Family)	31
1-14	Xanthic Ferralsol (Tungau Family)	33
1-15	Rhodic Ferralsol (Pinianakan Family)	33
1-16	Humic Podzol (Karamatoi Family)	33
1-17	Gleyic Podzol (Baiayo Family)	33

LIST OF TEXT MAPS

1-1	Reconnaissance Soil Survey	5
1-2	Physiography	13
1-3	Geology	15

LIST OF SEPARATE MAPS

The soils of Sabah. Scale 1:250 000 (ten sheets)

NB 50-3	Pulau Banggi
NB 50-6	Tuaran
NB 50-7	Sugut

NB 50-9	Labuan
NB 50-10	Kota Kinabalu
NB 50-11	Sandakan
NB 50-12	Dent Peninsula
NB 50-14	Pensiangan
NB 50-15	Tawau
NB 50-16	Semporna

Introduction to Volumes 1-5

Introduction to Volumes 1-5

PREFACE

This report is published with the permission of the Governments of Malaysia and Sabah. It presents the results of the reconnaissance soil survey of Sabah, together with a soil map of Sabah at a scale of 1:250 000, and describes in detail the soils surveyed by the Land Resources Division since 1967. Draft reports of the LRD surveys were presented to the Government of Sabah in 1972 and 1973.

A general assessment of the suitability of the soils for agricultural development is made in the present Land Resource Study and a detailed land capability classification of Sabah will be the subject of a subsequent report.

The present Land Resource Study is divided into five volumes as shown below:

Volume 1	Classification and description (with an introduction to Volumes 1-5). B D Acres, R P Bower, P A Burrough, C J Folland, M S Kalsi, P Thomas and P S Wright. This volume is accompanied by maps of the soils of Sabah.
Volume 2	Sandakan and Kinabatangan Districts. B D Acres and C J Folland.
Volume 3	Western Parts of Tawau and Lahad Datu Districts. P S Wright.
Volume 4	South-Western Districts. R P Bower, P A Burrough, M S Kalsi and P Thomas.
Volume 5	References and appendixes. B D Acres, R P Bower, P A Burrough, C J Folland, M S Kalsi, P Thomas and P S Wright.

Readers of the report as a whole will note that some material appears in nearly identical form in several volumes especially within the descriptions of the soil associations in Volumes 2, 3 and 4. This is done to improve the practical utility of these volumes. Volume 1 however does contain much detailed material on the soil units which is not repeated elsewhere.

ACKNOWLEDGEMENTS

We wish to express our appreciation to the Director and all members of the staff of the Department of Agriculture, Sabah, who were in any way involved in the Land Resources Division Soil Survey Project; we thank them for their unfailing assistance and interest.

We also wish to acknowledge the contribution of the following soil surveyors whose work has been used in the preparation of the State maps and Volumes 1 and 5 of this study: A W Allen, R G Barber, J Belsham, A D L Hooper, D W Ives, D W McCredie, T R Paton and F Wilson.

Special mention must be made of the support given by the staff of the following State Government Departments: the Forestry Department for vegetation identification; the Geology Department for rock identification; the Lands and Surveys Department for maps and photographs; the Marine Department for the use of Government launches; the Medical Department for medical attention; the Public Works Department for accommodation and transport; the State Archives for records and the Residents and District Officers for administrative arrangements.

We also thank the Soil Survey and Land Use Survey sections of the Malaysian Department of Agriculture for discussion and information on the Sabah land use survey; the Malaysian Meteorological Service and Department of Statistics for permission to quote climatic and population data and the Royal Malaysian Air Force for the use of aircraft. We thank the Editorial Board of the *Journal of Tropical Geography* Singapore, for their kind permission to print the physiographical text map in Volume 1.

We were visited by Dr J Coulter, the Land Resources Division Tropical Soils Liaison Officer stationed at Rothamsted Experimental Station, Dr C Sys and Dr H Eswaran of the Rijkuniversiteit, Gent, Belgium, and Dr E A Fitzpatrick, University of Aberdeen, and to them we are grateful for constructive criticism and advice. We also thank Mr T R Paton, Macquarie University, North Ryde, New South Wales, one of the original soil surveyors in Sabah, then North Borneo, for his constructive criticism of the text.

ABSTRACT

The study comprises the results of the reconnaissance soil survey of Sabah, Malaysia, and in particular describes the soils which have been surveyed by members of the Land Resources Division.

Volume 1 summarises the classification of Sabah soils. The physical background is outlined and the soil-forming processes are related to the classification. Thirteen groups of soil units are defined according to the FAO system and criteria for their separation into soil families and lower categories are listed. The soils are each described in terms of the presence and arrangement of diagnostic horizons. The soil units are also grouped into soil associations for mapping purposes. Fifty-one associations are described in terms of distribution, extent, landforms, parent materials, and soil units contained. The soil map of Sabah comprises 10 sheets at a scale of 1:250 000.

Volumes 2, 3 and 4 describe the soils in the districts surveyed by the Land Resources Division. The volumes follow similar patterns and contain introductory statements on geographical background. Soil associations are described in terms of distribution, extent, soil-forming factors and the soil units comprising the associations. The physical and chemical characteristics of the soil units are summarised. The agriculture of the districts is discussed and recommendations are made concerning agricultural development.

Volume 5 comprises references and appendixes common to the whole study.

RÉSUMÉ

Cette étude (Tomes 1-5) comprend une reconnaissance pédologique de Sabah, Malaisie, et décrit en détail les sols etudiés par les pédologues de la Land Resources Division.

Tome 1 comprend la classification des sols de Sabah. Les éléments fondamentaux du milieu physique et les rapports entre la pédogénèse et la classification des sols sont indiqués. Les unités de sol sont définies suivant le systéme FAO et disposées en treize groupes. Les critères pour la division des unités en familles et pour la subdivision de ces familles sont indiqués. Les horizons diagnostiques des sols sont décrites. Pour la préparation des cartes, les unités sont groupées en associations de sol et on décrit la répartition, la superficie, la topographie, les roche-méres, et les unités de sol de chacune des 51 associations. La carte pédologique de Sabah comprend 10 feuilles à l' échelle de 1: 250 000.

Les Tomes 2, 3 et 4 décrivent, pour trois régions de Sabah, les sols relevés par les pédologues de l'LRD. Chaque volume contient des descriptions introductoires du milieu géographique et des descriptions détaillées des associations. Les caractères physiques et chimiques des unités de sol sont résumés. On discute l'utilisation actuelle et potentielle des régions et on préconise des mésures pour la mise en valeur de la région.

Tome 5 comprend les annexes et la bibliographie. Un résumé plus détaillé de Tome 1 se trouve dans la premiére Partie de ce tome-ci.

LIST OF CONTRIBUTORS

B D ACRES	Formerly with the Western Region of Nigeria, Ministry of Agriculture, as a soil surveyor. Joined the Land Resources Division in 1967.
R P BOWER	Formerly with the Ministry of Agriculture as an advisory soil chemist and with the Department of Geography, University College of Wales, as a lecturer in Pedology. Joined the Land Resources Division on contract in 1971 and is now working for Bookers Agricultural and Technical Services Ltd, London.
P A BURROUGH	Formerly Demonstrator in the School of Geography, Oxford University. Joined the Land Resources Division in 1970 and is now a lecturer at the School of Geography, University of New South Wales.
C J FOLLAND	Formerly with the Soil Survey of England and Wales and the Lancashire County Planning Department. Joined the Land Resources Division in 1967. Responsible for the preparation of this study from original drafts submitted to the Sabah Government. Now Organising Secretary (Expeditions) of the Brathay Exploration Group, Ambleside, Cumbria.
M S KALSI	Senior soil scientist in the Sabah Department of Agriculture. Worked closely with the Land Resources Division project in Sabah.
P THOMAS	Formerly soil surveyor with the Western Region of Nigeria, Ministry of Agriculture, with Huntings Technical Services Ltd and with the Department of Agriculture, Sabah. Joined the Land Resources Division in 1967 and became Manager of the Sabah Regional Soil Survey and Land Capability Classification Project in 1969.
P S WRIGHT	Joined the Land Resources Division on contract in 1971 and is now with the Soil Survey of England and Wales.

HISTORY OF THE STUDY

Systematic soil surveys of Sabah began in 1953 when T R Paton and A W Allen were appointed to the Department of Agriculture. The first surveys were those in the Ranau, Lohan and Kundasang areas (Allen, 1955) and the Keningau Plain (Allen and Forster, 1956), the main purpose being to assess the areas for an expansion of rice cultivation. The soils were classified as soil series according to parent materials and stages of weathering.

Between 1953 and 1959 a broad reconnaissance survey was carried out in the Semporna Peninsula (Paton, 1963) (Text Map 1-1). The soils were defined as soil families and subfamilies, the former being defined according to the age of the soil parent materials and certain geomorphological features. Subfamilies were distinguished according to the composition of the parent materials.

From 1962 until 1964 the United Nations undertook natural resource surveys in the Labuk valley (Text Map 1-1). The soil survey incorporated work which had been carried out by the Department of Agriculture in the Lower Labuk and Ranau areas. Soil series and soil associations were mapped and were classified with emphasis on diagnostic profile characteristics and topographic position (Hooper and Ives, 1964).

At this time reconnaissance soil surveys were carried out in the east of the Lahad Datu District and in the northern parts of the Labuk and Sugut Districts by the Department of Agriculture (Text Map 1-1) (Thomas, 1967a and McCredie, 1970a) the soils being classified according to the soil units described in the Soil Map of the World legend (FAO, 1964). Great Soil Groups of this system were divided into soil families by differences in parent materials. In 1964 a soil map of Sabah was published at a scale of 1:50 000 with supporting text (Thomas and Allen, 1966).

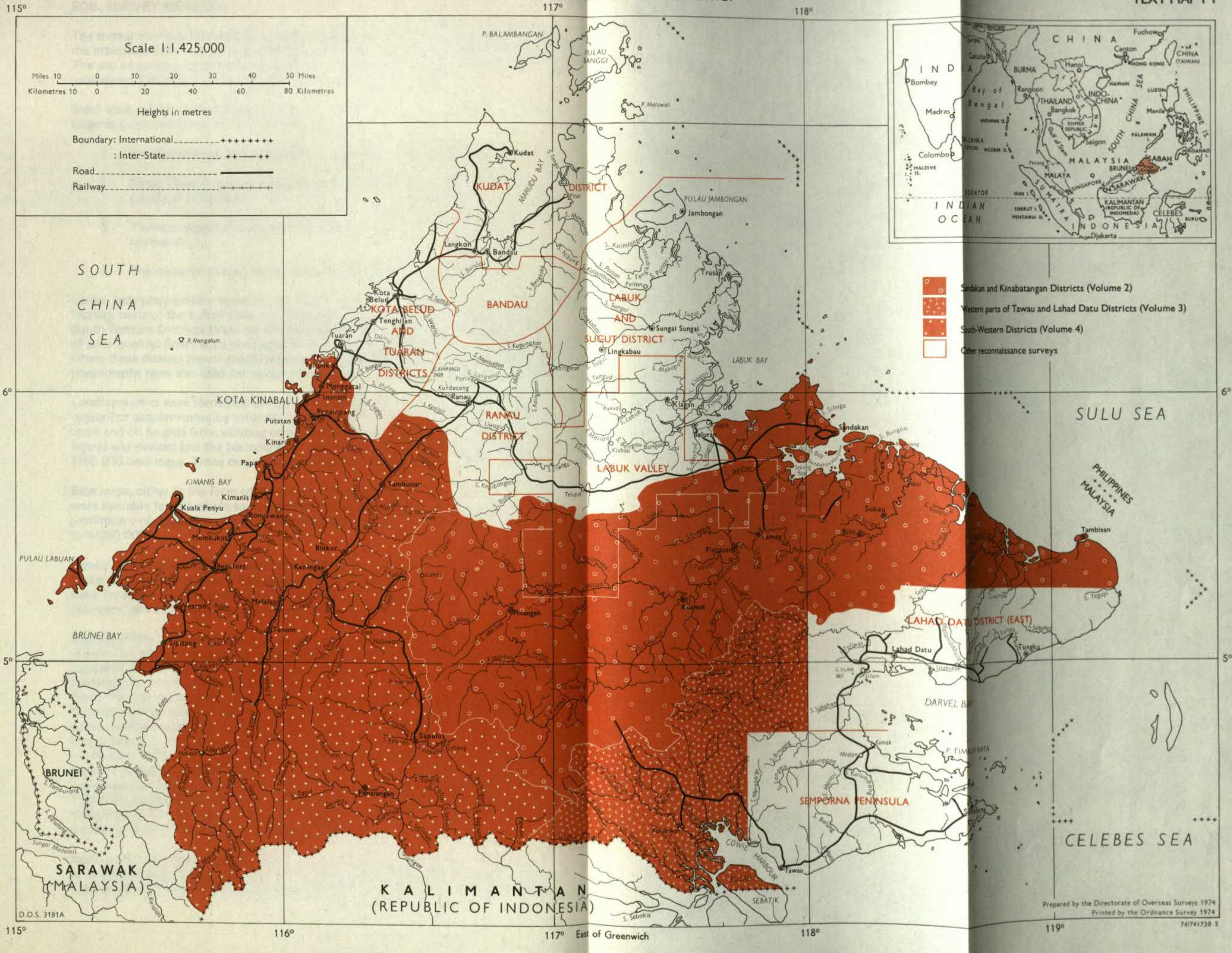
Semi-detailed surveys were undertaken between 1964 and 1967 by the Department of Agriculture mainly on proposed settlement schemes (Barber, 1966a, b and c; Barber and Thomas, 1965; McCredie, 1965, 1966, 1967a and b; Thomas, 1963, 1967b; Thomas and Barber 1964).

Further reconnaissance surveys began in 1967 when, under the auspices of the Colombo Plan, work in the Tuaran and Kota Belud Districts and parts of the Kudat District were surveyed (Text Map 1-1) (Wilson, 1969a and b; Belsham, 1969). Here, soil series and phases of series were mapped wherever map scales and ground control permitted, but in most of the area soil series could not be shown separately and the map units were generally complexes of 2 or more soil series. At the same time B D Acres and C J Folland of the Land Resources Division were seconded to the Department of Agriculture, under Columbo Plan Technical Assistance, to do a reconnaissance survey of the Sandakan and Kinabatangan Districts.

The present study originated in November 1969 when an official request was received from Sabah for the Land Resources Division to take over responsibility for the regional soil survey programme and to incorporate it into a soil survey and land capability classification project for the whole state. P Thomas, who had earlier been seconded from the Land Resources Division to Sabah under Colombo Plan Technical Assistance to undertake land capability classification studies, became project manager. He continued with the land capability classification, which will be reported in a separate study, and with R P Bower and P A Burrough completed the soil survey of the South-Western Districts (see Volume 4). P S Wright surveyed the western parts of the Lahad Datu and Tawau Districts (Volume 3) and B D Acres and C J Folland completed the Sandakan and Kinabatangan Districts (Volume 2). D W McCredie of the Department of Agriculture surveyed the Ranau District and the area south of Bandau in the Kudat District (McCredie, 1971) (see Text Map 1-1). The reconnaissance soil survey of the whole state was completed in 1972.

Preliminary drafts of Volumes 2, 3 and 4 were submitted to the Sabah Government in 1972 and 1973. They were accompanied by drafts of the 1:250 000 soil maps and the 1:50 000 field sheets. In addition to participating in and completing the mapping programme for the whole State the Land Resources Division project team was required to correlate its work with previous surveys in order to produce a classification of Sabah soils. Because the various surveys undertaken had used different classifications it was necessary to adopt a new system and the classification used by the FAO for the Soil Map of the World Project (Dudal, 1968) was selected; all previous soil descriptions were correlated with this. This work was not completed until after the Land Resources Division surveyors had returned from Sabah so that the classification which is contained in Volume 1 of this study shows considerable changes from the preliminary draft which was submitted in 1972. Major changes in soil family designations are listed in Volume 5, Appendix 6.

SABAH RECONNAISSANCE SOIL SURVEY TEXT MAP 1-1



SOIL SURVEY METHODS

The survey methods followed by surveyors of the Land Resources Division combined the interpretation of air photographs with field observations. (Acres and Folland, 1968). The aim of photo interpretation is to arrive at a classification of land surfaces which by subsequent fieldwork, can be transferred into soil mapping units.

Small-scale photographs at scales ranging from 1:48 000 to 1:64 000 were preferred to larger scale photographs for the following reasons:

1. A comparatively small number of photos were handled.
2. Detail identifiable was consistent with that which could be mapped at a scale of 1:250 000
3. The best overall picture could be gained of landform distribution and relationships.
4. The majority of base maps were compiled from these photographs.

Larger scale photography (mostly 1:25 000) was used throughout the survey of the Western parts of the Lahad Datu and Tawau Districts (Volume 3) and in parts of the South-Western Districts (Volume 4) where small-scale photography was unavailable or of poor quality. Small scale photographs were supplemented by larger scale photographs where these showed recent roads, railways, settlements and land use; these larger-scale photographs were also used for navigation and field orientation in some remote areas.

Landform units were identified using the photo elements of relief, drainage, slope and vegetation supplemented by information on parent materials provided by geological maps and on heights from existing contoured topographic maps; a physiographic legend was devised and the boundaries of the landform units were transferred to 1:50 000 base maps. These maps were used mainly in the planning of fieldwork.

Base maps, either in the form of contoured topographic sheets or preliminary plots were available for the whole survey area by 1969; any discrepancies between adjacent preliminary-plot sheets and contoured topographic sheets were resolved when reduced to 1:250 000.

Ideally field reconnaissances were carried out prior to full-scale surveys to investigate access by river, rail, road and footpath, to become familiar with the area concerned, to meet for example, local government officers, village headmen and timber camp managers, and to make initial examinations of any soil exposures.

Because of the forested nature of much of Sabah, field survey was based on the observation of soils along cut traverses. Traverses were selected in the most easily accessible parts of particular landform units so that they crossed as many as possible of the landform unit boundaries and representative areas of the units being investigated. Every traverse started from a point that could be located on photograph, map and on the ground; they rarely exceeded 5 km (3 mi), the maximum distance that could be conveniently surveyed by a soil scientist in a day, but traverses up to 20 km (12 mi) in length were cut into some of the more remote areas. In some remote areas unprepared routes were followed by navigating from photographs. Where road access was good, roadside exposures were examined and in the interior valleys of Tenom, Keningau and Tambunan soil sample pits were sited at random by placing a dotted template over 1:25 000 scale photographs. In general, access was by river and by air, helicopters being used in the most remote areas. Radio sets were used for communication between survey parties and between survey party and office.

Advance field parties consisting of 1 or 2 assistants, 10-15 men and 2 boatmen selected campsites, located and cut the traverses and carried out routine soil descriptions at 30 m (100 ft) intervals along the traverses. The soil scientists made further observations and selected and sampled pits dug to 125 cm (50 in); soil samples for laboratory analysis, soil monoliths and geological samples were collected. Preliminary soil association descriptions were prepared in the field for each landform unit investigated.

At selected sites forest types were sampled by assistants from the Forest Department; summary notes on the forest types were supplied by the Forest Ecologist.

After fieldwork the photographs were re-examined; while the physiographic parameters provided a convenient framework for classifying landforms during preliminary photo-interpretation, fieldwork showed that relief divisions in particular had given a duplication of mapping units that were not based on soil differences. In a few cases new mapping units were revealed that had not been previously identified. A flexible approach was thus essential and both boundaries and the legend were continually modified as required. Soil association boundaries were plotted on the 1:50 000 base maps and reduced photographically to a scale of 1:250 000.

Volume 1, Parts 1-5

Part 1

Introduction

ACKNOWLEDGEMENTS

Sources of data are quoted in the text and full acknowledgements are given in the Introduction to Volumes 1-5 at the beginning of this study.

ABSTRACT

The volume summarises the classification of Sabah soils. The physical background is outlined and the soil-forming processes are related to the classification. The soils are classified according to the FAO scheme. Thirteen soil units are described in the following order: Histosols, Lithosols, Fluvisols, Gleysols, Regosols, Rankers, Podzols, Ferralsols, Rendzinas, Acrisols, Luvisols, Cambisols and Arenosols. The criteria used to separate the soil units into soil families and lower categories are discussed. Soil families are each described in terms of the presence and arrangement of diagnostic horizons and their chemical characteristics. Representative soil profiles are contained in Volume 5, Appendix 1. The soil units are grouped into 51 soil associations for mapping purposes. These are briefly described in the following order: soil associations on alluvium; mudstone, sandstone and miscellaneous rocks; limestone and acid, intermediate, basic and ultrabasic igneous rocks. The soil map of Sabah, accompanying this report, comprises 10 sheets at a scale of 1:250 000.

RÉSUMÉ

Ce volume traite de la classification des sols de Sabah. Le milieu physique est esquissé et les rapports entre la pédogénèse et la classification des sols sont expliqués. La classification suit le système FAO. Treize groupes d'unités de sol sont décrites dans l'ordre suivant: Histosols, Lithosols, Fluvisols, Gleysols, Regosols, Rankers, Podzols, Ferralsols, Rendzinas, Acrisols, Luvisols, Cambisols, Arenosols. Les critères pour subdiviser ces unités sont discutés. Les familles de sol sont décrites en fonction de la présence et la disposition des horizons diagnostiques et de leurs caractères chimiques. Les profils typiques sont présentés dans un Annexe de Tome 5.

Les unités de sol sont groupées en 51 associations de sol aux fins de la préparation de la carte pédologique. Les associations sont brièvement esquissées dans l'ordre suivant: associations sur alluvion, argilolithe, grès et roches diverses, calcaire, et roches ignées (acides, basiques et ultrabasiques). La carte pédologique de Sabah, qui accompagne ce volume, comprend 10 feuilles à l'échelle 1:250 000.

Part 2

Geographical background

SETTLEMENT AND COMMUNICATIONS

The State of Sabah, Malaysia occupies the northern portion of the island of Borneo. Its immediate neighbours are Sarawak, also a state in the Federation of Malaysia, Brunei, a state under British protection and Kalimantan, which is a part of Indonesia. The total area of Sabah is 76 100 km^2 (29 388 mi^2). The population at the time of the 1970 Census was 655 622 with settlements mainly on the east and west coasts, the interior plains and along the main rivers. Most of the interior and eastern parts of Sabah are uninhabited and consist of mountain ranges and broad valley tracts covered in dense forest. Kota Kinabalu, the state capital, is situated on the west coast. It has a population of 61 645. Sandakan, on the east coast has a population of 72 430 and is the largest town, having a fine port on the northern shore of Sandakan Harbour. Tawau, Lahad Datu and Kudat are also important ports on the east coast (Text Map 1-2).

The population comprises many races, the Kadazans being the largest group and forming about one third of the total. They live mainly on the west coast and on the interior plains. The Bajaus are concentrated on the west coast and in scattered settlements on the east coast. The Muruts live mostly in the south-west, particularly in the remote parts between Keningau and the borders of Sarawak and Kalimantan. The Chinese, who make up about one quarter of the population, are mainly town dwellers, but there are significant numbers of smallholders in rural areas.

Road networks radiate from the main towns, the majority of which are now linked by road. Kota Kinabalu, for example, is linked to Kudat in the north and Sipitang in the south by the West Coast Highway. It is also linked to Sandakan by the recently completed East-West Highway and to Tambunan and Keningau by a recently completed road across the Crocker Range. On the east coast a major network links Tawau, Kunak, Semporna and Lahad Datu and it is proposed to link this to the other networks by constructing a road from Lahad Datu to the East-West Highway. In addition to constructing roads, the main towns are all served by regular internal air services and there are also international flights to Singapore, West Malaysia and Hong Kong.

The rivers are still vital for communications particularly on the east coast. The Kinabatangan, which is the longest river, follows a course of over 550 km (340 mi) from its source in the Trusmadi Range to the sea south-east of Sandakan. It is navigable by large launches as far as Pintasan and as far as Pinangah by shallow draught boats powered by outboard engines.

CLIMATE

The climate is hot and humid throughout the year and although Sabah lies outside the typhoon belt the coastal areas are occasionally affected by severe tropical storms. The average annual rainfall ranges from about 1 780 mm (70 in) to about 3 800 mm (150 in). The highest rainfall is in the south-west (Beaufort and Labuan) and the lowest

is in the interior (Tenom, Keningau and Tambunan) and at Tawau on the south-east coast. The contrasts in regional rainfall reflect the occurrence of 2 main seasons; the north-east monsoon begins in November and lasts until March and it is during this season that the north-east coast experiences its heaviest rainfall; the south-west monsoo prevails from May until September. The temperature varies little with the season and averages about 27°C (80°F) near sea level. Surface temperatures inland fall at a rate of about 1.5°C (3°F) for every 300 m (100 ft) increase in altitude so that above about 1 200 m (4 000 ft) there is a change from Tropical Rainy Climate to Warm Temperate Rainy Climate (Trewartha, 1954); the latter affects much of the Crocker and Trusmadi Ranges above 1 200 m (4 000 ft). Climatic data are very limited, but records of a reasonable length are available for Labuan, Kota Kinabulu, Kudat, Beaufort, Tenom, Sandakan, Tawau and Tambunan. Climate is discussed at length in Volumes 2, 3 and 4.

PHYSIOGRAPHY

Sabah can be divided into 4 main physiographic regions, namely the Western Lowlands the Western Cordillera, the Central Uplands and the Eastern Lowlands (Collenette, 1963). The Western Lowlands include the foothills, plains and islands to the west of th Crocker Range. The Western Cordillera comprises a belt of mountainous country about 80 km (50 mi) in width parallel to the west coast. It includes the Crocker, Trusmadi, Witti and Maligan Ranges and associated intermontane plains and valleys. The Crocker Range is one of the main geographical features of the country and it culminates in Gunong Kinabalu, which at 4 101 m (13 455 ft) is the highest mountain in south-east Asia. The Central Uplands comprise extensive tracts of mountainous country to the east of the Western Cordillera, including the Labuk, Kuamut, Segama and Tawau Highlands. The Eastern Lowlands stretch from the Bengkoka Peninsula in the north to the Semporna Peninsula in the south and include extensive tracts of moderate to low hills, the broad valleys of the Sugut, Labuk, Kinabatangan and Segama rivers and extensive deltas (Text Map 1-2, based on a map of P Collenette (1963) in the *Journal of Tropical Geography*, volume 17, Singapore, with whose permission the present map is published). Landforms are discussed and illustrated by maps in Volumes 2, 3 and 4 and they form the basis of the majority of soil associations described in Part 5 of this volume and in Volumes 2, 3 and 4.

GEOLOGY

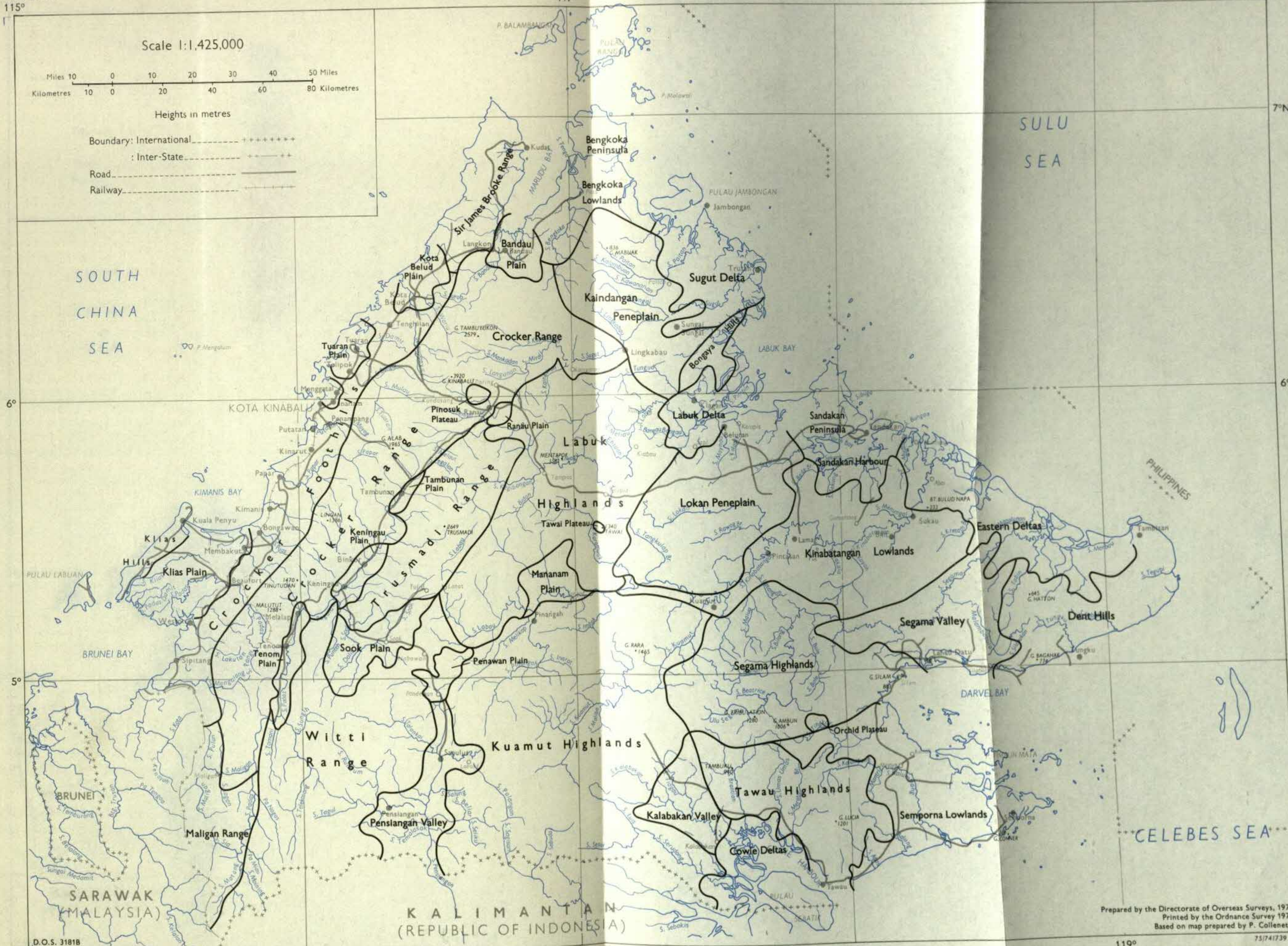
The geology of Sabah is described in the Memoirs of the Geological Survey of the Borneo Region of Malaysia; the main geological formations are shown in Text Map 1-3

The oldest rocks in Sabah, referred to collectively as Crystalline Basement, include granodiorite, diorite, gabbro, migmatite, amphibolite, hornblende, gneiss, hornfels and schist; they only occur in the Tawau and Lahad Datu Districts, notably in the Segama catchment.

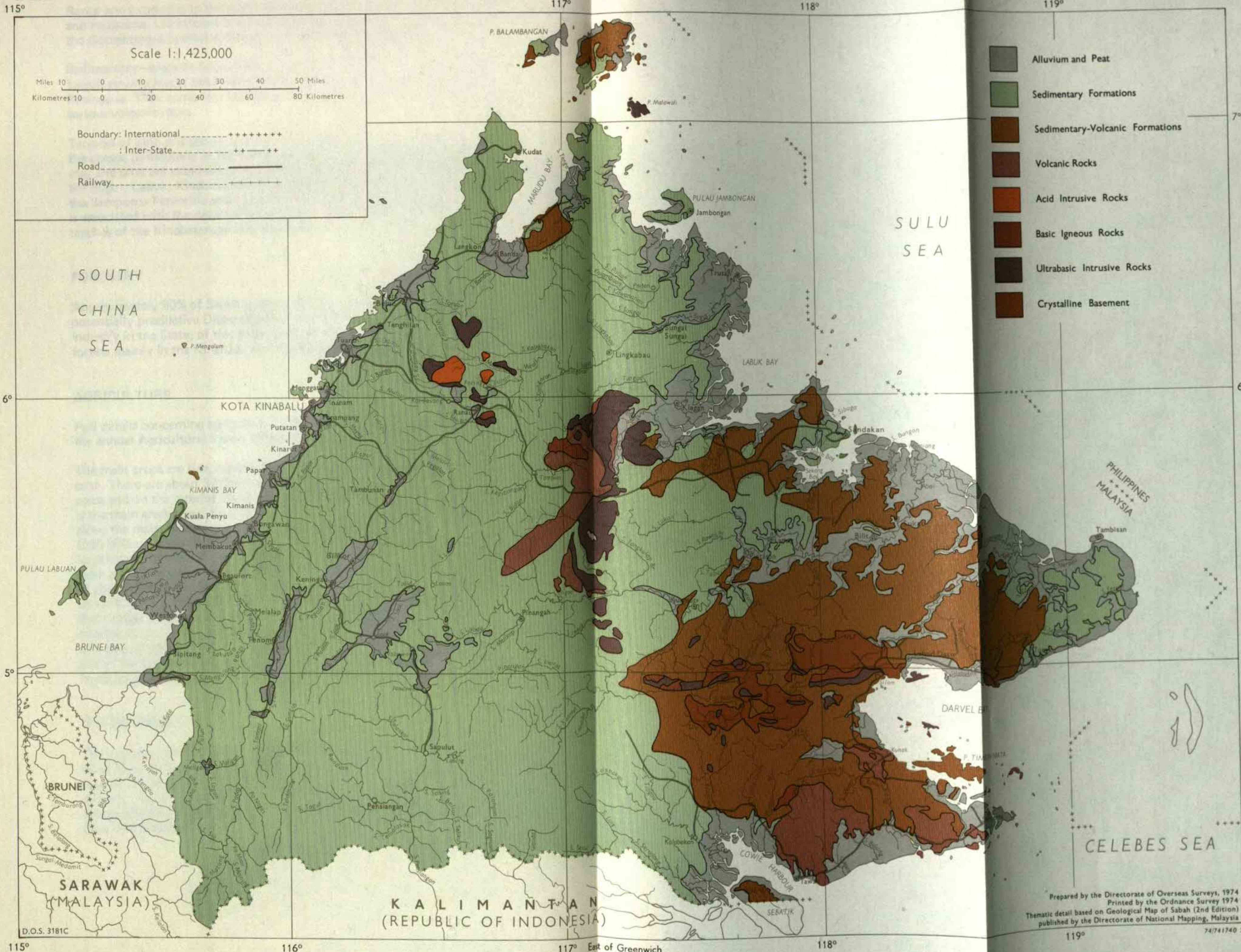
Intrusive igneous rocks occur in 3 main areas, namely Kinabalu, the Labuk Highlands and in the Tawau and Lahad Datu Districts. Ultrabasic igneous rocks, composed largel of serpentinised periodotite, are most extensive forming, in particular, the mountain range in the Labuk Highlands extending from Gunong Rara in the south to Suroh Sur in the north. Basic igneous rocks such as gabbro, dolerite and diorite occur sporadical in the 3 areas referred to, but acid igneous rocks including granodiorite, adamellite an tonalite are restricted to the Kinabalu area, forming in particular Mount Kinabalu.

Volcanic rocks occur in the Labuk Highlands and in the Semporna Peninsula. In the former they comprise spilite and basalt lavas and in the latter comprise olivine basalt, dacite lavas, andesite, volcanic breccia, tuff and pyroclastic rocks.

Sedimentary formations are widespread in Sabah; they range in age from the Eocene the Pliocene and comprise sandstone, mudstone, shale, clay and limestone. The Crock formation is by far the most extensive, forming most of the west coast and the Crock


Scale 1:1,425,000
Miles 10 0 10 20 30 40 50 Miles
Kilometres 10 0 20 40 60 80 Kilometres
Heights in metres
Boundary: International
: Inter-State
Road
Railway
SOUTH CHINA SEA
SULU SEA
CELEBES SEA
BRUNEI BAY
DARVEL BAY
LABUK BAY
KIMANIS BAY
PULAU LABUAN
PULAU JAMBONGAN
P. BALAMBANGAN
P. Malawali
P. Mengalum
PHILIPPINES
BRUNEI
SARAWAK (MALAYSIA)
KALIMANTAN (REPUBLIC OF INDONESIA)
KOTA KINABALU
Sir James Brooke Range
Bengkoka Peninsula
Bengkoka Lowlands
Bandau Plain
Kota Belud Plain
Sugut Delta
Kaindangan Peneplain
Crocker Range
Bongaya Hills
Tuaran Plain
Pinosuk Plateau
Ranau Plain
Labuk Delta
Labuk Highlands
Sandakan Peninsula
Sandakan Harbour
Crocker Foothills
Tambunan Plain
Trusmadi Range
Lokan Peneplain
Tawai Plateau
Keningau Plain
Klias Hills
Klias Plain
Eastern Deltas
Kinabatangan Lowlands
Mananam Plain
Segama Valley
Dent Hills
Sook Plain
Tenom Plain
Penawan Plain
Segama Highlands
Orchid Plateau
Witti Range
Kuamut Highlands
Tawau Highlands
Kalabakan Valley
Semporna Lowlands
Pensiangan Valley
Maligan Range
Cowie Deltas
3920 G. KINABALU
G. TAMBUYUKON 2579
G. TRUSMADI 2649
Kudat
Langkon
Kota Belud
Tenghilan
Tuaran
Telipok
Menggatal
Penampang
Putatan
Kinarut
Papar
Kimanis
Kuala Penyu
Bongawan
Membakut
Beaufort
Tenom
Sipitang
Tambunan
Keningau
Pinangah
Lingkabau
Jambongan
Sandakan
Sukau
Lamag
Pintasan
Kuamut
Lahad Datu
Tungku
Tawau
Semporna
Kalabakan
Sapulut
Pensiangan
Tamisan
Prepared by the Directorate of Overseas Surveys, 1974
Printed by the Ordnance Survey 1974
Based on map prepared by P. Collenette
D.O.S. 3181B
75/741739 S
115° 116° 117° 118° 119°
7°N 6° 5°
East of Greenwich

SABAH GEOLOGY TEXT MAP 1-3



Range and extending to the north-east coast. It comprises interbedded sandstone, shale and mudstone. Limestones form minor parts of many formations, but are dominant in the Gomantong Limestone, Togopi and Timohing Formations.

Sedimentary–volcanic formations are dominant on the east coast, extending from the Labuk estuary across the Kinabatangan and Segama to the Dent and Semporna Peninsulas. They comprise sandstone, mudstone, slump breccia, chert, spilite and various volcanic rocks.

Terraces of sand and gravel occur in the interior plains, along the main rivers and on the coasts, particularly in the north-east and south-east. Recent alluvial deposits of clay and sand are extensive along the east coast in the lower reaches and estuaries of the Sugut, Labuk, Kinabatangan and Segama, around Cowie Harbour and the south of the Semporna Peninsula and along the west coast, notably on the Klias Peninsula. Peat is associated with the recent alluvial deposits in the Klias Peninsula and the lower reaches of the Kinabatangan and Segama.

FORESTRY

Approximately 80% of Sabah is under forest, mostly consisting of productive, or potentially productive Dipterocarps, which are the basis of the flourishing timber industry in the State; of this total, mangrove forests along the coasts, and montane forests mainly in the Kinabalu and Trusmadi regions each cover about 5%.

AGRICULTURE

Full details concerning agriculture in Sabah are contained in the Annual Reports and in the annual Agricultural Statistics published by the State Department of Agriculture.

The main crops are rice, rubber, coconut, oil palm and cocoa. Rice is the most important crop. There are about 32 000 ha (80 000 ac) of wet rice grown mainly on the west coast and on the interior plains and about 10 000 ha (25 000 ac) of hill rice. Hill rice is the main crop grown by shifting cultivators notably in the Crocker Range and also along the main rivers in the east. Rubber covers an area of about 105 000 ha (260 000 ac). Most of it is grown by smallholders on the west coast and there are also large estates notably in the interior, on the west coast and also in the Tawau area. The main areas of coconut production are Kudat, Tawau and Lahad Datu, with a total area of about 56 000 ha (140 000 ac). The oil palm acreage has expanded rapidly from about 800 ha (2 000 ac) in 1961 to about 43 000 ha (106 000 ac) in 1971; most of the acreage has been planted by estates and also by government settlement schemes notably in the Tawau and Sandakan Residencies. Cocoa, too, has expanded in acreage to a total of about 4 500 ha (11 000 ac). It is grown mainly in the Tawau Residency and in the Labuk Valley. Other crops grown include hemp, coffee, tobacco, sago palm, fruits, vegetables, maize, tapioca, sweet potato and sugar cane.

THE ECONOMY

The economy of the State is based on timber, which accounts for about three-quarters of all exports. Of the agricultural products, rubber is the most important export, but exports of palm oil are increasing rapidly. Copra and cocoa beans are also significant exports. The recent discovery of commercially exploitable copper deposits near Ranau has added impetus to further prospecting and both petroleum and gas have been discovered offshore.

Part 3

Soil formation

Climate is the dominant factor in soil formation in Sabah, both directly through the elements of rainfall and temperature and indirectly through its control over vegetation zones. This is seen in the association of Dipterocarp forest with the Tropical Rainy Climate over most of Sabah and the change to Heath Montane Forest where altitude causes a change to a Warm Temperate Rainy Climate.

Three important soil-forming processes, namely weathering, clay translocation and leaching are directly affected by climate. Physical weathering is comparatively unimportant, because the protective forest cover shields the land surface from extremes of heat. Chemical weathering, in which water is the principal agent, is far more important and includes the chemical processes of hydration, hydrolysis, solution, oxidation, reduction and clay mineral formation. The rate of these chemical reactions is affected by temperature and with mean temperatures of about 29°C (84°F), conditions for weathering are at an optimum. Intense weathering over long periods of time or in iron-rich parent materials leads to the process of ferralisation in which bases and silica are removed by leaching to give a relative accumulation of aluminium and iron oxides accompanied by the formation of 1:1 lattice clays of the kaolinite group. A horizon in which most of the clays have been weathered to kaolinite and sesquioxides, and which as a result has a very low cation exchange capacity, is called an oxic horizon (see definitions of soil horizons in Volume 5, Appendix 2).

The physical processes that result in the movement of particles through soil profiles include leaching and clay translocation. Leaching is intense under high rainfall conditions and leads to the formation of soils of low base status; soils with high base status are usually formed on base-rich parent materials. The only counteracting process is the uptake of nutrients by plants and the subsequent deposition at the surface in organic matter. The majority of soil profiles show that the available nutrients are greatest per unit weight of soil at the surface and this is reflected in the values for base saturation. Inténsive leaching of highly siliceous parent materials, such as sandstone and coarse-textured alluvium associated with surface layers of acid humus results in the process of podzolisation, in which the removal of bases and sesquioxides leads to an increase in the proportion of silica in the profile and the formation of bleached or albic horizons; humus and sesquioxides accumulate at depth to form spodic horizons.

Clay translocation leads to the formation of argillic horizons, which are recognised by an increase in the fine clay fraction with depth and the presence of cutans on ped surfaces and in pores. An increase in the fine clay fraction may also be due to clay formation in the soil profile, but it is often not possible to ascertain in the field whether the clays are illuvial or formed *in situ* and studies of thin sections are usually required. The argillic horizon forms below an eluvial horizon, but it may be at the surface if the soil has been truncated by erosion; in this situation there is often little evidence of a change of texture with depth.

2 Vegetation acts as a soil-forming factor chiefly by supplying organic matter to the soil, where it accumulates as organic horizons. Plant remains fall onto and are largely decomposed at the surface, so that there is usually a decrease in soil organic matter content with depth. Organic matter, however, is also present within many profiles as concentrations in root and animal channels of decayed plant roots or material carried down by fauna, notably worms and termites. In addition organic matter is carried downwards by soil water and is redeposited as coatings on pores and structure faces.

It is well established (Richards 1952) that under dipterocarp forests below about 900 m (3 000 ft) the decomposition of wood, bark and leaves by bacteria is so rapid that it keeps pace with the continuous addition of plant materials to the surface. As a result surface accumulations of organic matter are generally very shallow. They comprise thin layers of leaf litter, chopped leaves and mixed humus and mineral particles. These shallow surface layers defined as ochric horizons average 3-5 cm (1-2 in) in thickness. Organic carbon contents in general average 2-4% but range from 1% upwards. Carbon/nitrogen ratios are also generally low, and percentage base saturation values of ochric epipedons are extremely variable.

Surface horizons which comprise humus intimately incorporated with mineral matter, and which have dark colours, high base saturation and well developed structure are defined as mollic horizons. Under hydromorphic conditions, which result mainly from the presence of high watertables, but also from continued wetness with associated fall of temperature at altitudes greater than about 900 m (3 000 ft), the decomposition of plant remains is retarded and partly decomposed organic matter accumulates at the surface. The surface horizons which result are referred to as histic O horizons. Deep accumulations of such organic matter are known as peat. The degree of humification of organic matter accumulating under hydromorphic conditions varies from being only slightly humified and consisting essentially of non-humified plant remains to very strongly humified organic matter lacking visible plant remains.

Surface horizons consisting of fresh and/or partly decomposed organic matter accumulated under predominantly aerobic conditions and having similar organic carbon contents to histic horizons are referred to simply as O horizons. They accumulate on sites where the bacterial decay of plant remains is curbed by conditions other than very poor drainage. Such conditions are satisfied for example under heath vegetation where extreme acidity of parent materials, very low nutrient levels and periodic conditions of extreme dryness retard plant decay. Under such conditions the O horizon comprises distinct layers of leaf litter, partly decomposed litter in which decomposition is proceeding, and wholly humified organic matter sharply separated from the underlying mineral soil.

3 Landform affects soil development directly through the nature of relief and its effect on erosion, deposition and soil moisture regimes. Erosional forces create the relief and slope of landforms and in turn slope affects the soil-forming processes active within the weathering mantle. The depth of soil on any slope represents the balance between the rate of weathering and the rate of removal by forces due to gravity including mass movement, surface wash and gully erosion. These forces are most active on steep slopes and the depth of soil on such slopes is in general less than on gentle slopes. Mass movement occurs on very steep slopes and is seen in the form of terracettes, screes and landslides. Slope wash results from surface runoff and takes place on slopes greater than 5^{o}, being most active on steeper slopes. On steep slopes, mass movement and slope wash produce unstable stony deposits in which profile development is periodically interrupted by further movement. The weakly developed horizons in these deposits are defined as cambic horizons and they also occur in alluvial deposits in the early stages of soil formation.

Slope is the main determinant of soil drainage in terms of removal of water by surface runoff, downward percolation into the soil and the presence of watertables. Excessively drained soils (see soil drainage categories in Volume 5, Appendix 3) occur on very steep slopes or on deep coarse-textured deposits unaffected by groundwater fluctuations. Well drained and moderately well drained soils occupy the majority of middle and upper slopes, while imperfectly drained soils occur on lower slopes affected by groundwater fluctuations. Imperfectly and poorly drained soils occur on valley floors, floodplains, low terraces and beaches where groundwater is near the surface.

Poorly and very poorly drained soils occur in backswamps and coastal swamps with high watertables. Fluctuating watertables result in alternate periods of reduction and oxidation in the soil horizons above the permanent groundwater level and ferric iron compounds, released by weathering, are reduced to ferrous compounds and change from red or yellow to grey. The process is known as gleying and is seen in the profile in the form of grey and rust mottles. Horizons in which gleying is the dominant process and which are mainly grey in colour are referred to as gleyic horizons. All iron compounds, however, are not gleyed when the soil drainage is poor, true gley colours perhaps being masked by residual colours of unreactive compounds. Iron compounds in the form of rust mottles may in time develop into concretions which, should they persist, act as nuclei for further iron concentration. In extreme cases the accumulation of iron compounds leads to the formation of plinthite, which on drying hardens irreversibly in the form of ironstone.

In the early stages of soil formation the nature of the parent material usually determines soil properties and soils lack diagnostic horizons; recent alluvial deposits in tidal swamps, meander belts and valley floors and recent beach deposits are examples of such parent materials. On steep slopes where there is active erosion profiles do not develop beyond the stage of shallow surface horizons overlying hard rock.

With time, soil forming processes become active and this is seen in the development of soils with cambic horizons. They occur on alluvial deposits and on a wide range of unstable colluvial deposits on steep slopes, where the normal processes of clay eluviation and illuviation are interrupted. The parent materials are in all cases young alluvial or colluvial deposits and the age of the geological formation from which they are derived is irrelevant.

Soils with gleyic horizons form irrespective of the age and nature of parent materials because the gleying process is dependent on site drainage. However, the majority are formed on alluvial deposits where watertables are continually high. In sites with fluctuating watertables cambic horizons are common and argillic horizons develop with time.

Soils with argillic horizons are the most widespread soils in the survey area; they are pedologically older than soils with cambic horizons, because they occur on more stable slopes, on which the normal processes of eluviation and illuviation can operate without interruption. Such soils occur on a wide range of parent materials of varying age including alluvium on floodplains and terraces, igneous rocks, sandstone, mudstone, limestone and tuffaceous rocks.

In pedological terms the only old soils which occur in the area are those with spodic and oxic horizons; in both cases the processes of soil formation have been accelerated by particular factors other than the age of the deposits on which they are developed. Soils with spodic horizons are formed on materials including comparatively recent beach sands, old terrace alluvia and stable slopes of sandstone. In all cases the presence of coarse-textured, largely siliceous deposits, has favoured the establishment of heath forests with associated accumulations of raw humus followed rapidly by podzolisation.

Soils with oxic horizons are normally associated with old land surfaces, which have undergone a complete cycle of weathering. In the survey area, however, the majority occur on steep slopes on colluvial deposits derived from ultrabasic rocks, in which ferralization has been rapid. It is thus the nature of the parent material rather than its age which has given rise to these pedologically old soils.

Part 4

Soil classification

Introduction to the soil units

The soils described in Sabah have been classified according to the scheme used by the FAO/UNESCO Soil Map of the World Project. The definitions of soil units used for the preparation of the first draft Soil Map of the World, at a scale of 1:5 000 000, were presented in the World Soil Resources Report No. 33 (Dudal, 1968). These definitions, together with the first draft soils map, were discussed at the 9th Congress of the International Society of Soil Science in Adelaide, Australia in August 1968. The results of these discussions were incorporated in World Soil Resources Report No. 37 (Dudal, 1969). Further testing of this classification is still in progress and the final definitions have yet to be published. However, an interim key to soil units has been issued (FAO 1970), in which diagnostic horizons are identified (see Volume 5, Appendix 2) and the soil units are classified by the presence or absence of these horizons within a depth of 125 cm (50 in) from the surface. These units are subdivided according to combinations of these horizons with other prominent specified soil properties, for example, base saturation, colour and presence of concretions.

In Sabah the soil units have been further subdivided into 'families' which are loosely defined as soil units formed on similar parent materials e.g. Gleyic Luvisols and Gleyic Acrisols formed on alluvium comprise the Buran and Inanam Families respectively. The soil families, which have been defined are listed in Table 1-1.

The criteria used to subdivide the soil families relate particularly to the arrangement and characteristics of diagnostic horizons, and therefore include physical and chemical properties such as drainage, colour, tecture and stoniness. The same criteria are not necessarily used throughout the classification; for example, compact E horizons which are used in the separation of families of Acrisols and Podzols do not occur in any of the other units and are therefore not considered.

This subdivision of families is at an early stage and reflects the nature of soil survey work which has been carried out in Sabah. Most of the mapping has been of a reconnaissance nature, at scales which have not permitted the mapping of individual soil series. The suggested subdivision of soil families which follows is therefore tentative, but forms the basis for future more detailed work, during which more precise definitions should be developed.

Twenty-six groups of soil units have been defined by the FAO (FAO, 1970) and of these 13 are recognised in Sabah. They are described in the following order: Histosols, Lithosols, Fluvisols, Gleysols, Regosols, Rankers, Podzols, Ferralsols, Rendzinas, Acrisols, Luvisols, Cambisols and Arenosols. Each description is preceded by the appropriate definition derived from the FAO key and is accompanied by a table illustrating the subdivision of the soil unit into soil families. In many cases figures illustrate the criteria for the further subdivision of the soil families. The soil associations in which the soil units have been mapped are also shown in tables. Profiles illustrating the various soil units are contained in Volume 5, Appendix 1.

TABLE 1-1 Soil family classification

Soil unit	Parent material	Family
Dystric Histosol	Peat	Klias Kaintano
	Sulphidic peat	Arang
Eutric Histosol	Calcareous peat	Mengalum
Lithosol		not named
Thionic Fluvisol	Sulphidic alluvium Alluvium	Weston Kalibong
Calcaric Fluvisol	Calcareous alluvium	Nunuyan
Dystric Fluvisol	Alluvium	Tenghilan
Eutric Fluvisol	Alluvium	Pegalan
Humic Gleysol	Calcareous alluvium Alluvium Sandstone Acid igneous rocks	Berhala Guan Kidukarok Wullersdorf
Thionic-humic Gleysol	Sulphidic alluvium	Bergosong
Calcaric Gleysol	Calcareous alluvium	Lari
Dystric Gleysol	Alluvium	Koyah
Thionic-dystric Gleysol	Sulphidic alluvium	Metah
Eutric Gleysol	Alluvium Mudflows	Bangawat Rasang
Thionic-eutric Gleysol	Alluvium	Libur
Calcaric Regosol	Calcareous alluvium	Usukan
Dystric Regosol	Alluvium	Tamanong
Eutric Regosol	Alluvium Alluvium derived from basic and ultrabasic rocks	Tanjong Lita Tanjong
Ranker	Acid igneous rocks	Kinabalu
Placic Podzol	Acid igneous rocks	Mesilau
Gleyic Podzol	Alluvium Sandstone	Baiayo Pa Sia
Humic Podzol	Alluvium	Karamatoi
Orthic Podzol	Alluvium Sandstone	Silimpopon Sibuga
Rhodic Ferralsol	Intermediate igneous rocks Ultrabasic igneous rocks	Apas Pinianakan
Xanthic Ferralsol	Alluvium Basic igneous rocks	Tungau Jarangan
Orthic Ferralsol	Alluvium derived from ultrabasic rocks	Nobusu
	Alluvium Ultrabasic igneous rocks Basic igneous rocks	Benuou Ambun Table
Rendzina	Limestone	Loc Sambuang

TABLE 1-1 (continued)

Soil unit	Parent material	Family
Gleyic Acrisol	Alluvium Tuffaceous rocks Sandstone and mudstone Mudstone	Inanam Koung Gunong Alab Masaum
Humic Acrisol	Sandstone and mudstone	Kiau
Ferric Acrisol	Alluvium Basic igneous rocks Sandstone and mudstone Mudstone	Lumisir Beruang Sipit Batang
Orthic Acrisol	Alluvium derived from basic and ultrabasic rocks Alluvium Basic and intermediate igneous rocks Tuffaceous rocks Chert Sandstone Sandstone and mudstone Mudstone	Katai Paliu Kinabutan Dagat Mensuli Kapilit Tanjong Lipat Kumansi
Gleyic Luvisol	Alluvium derived from basic and ultrabasic rocks Calcareous alluvium Alluvium Mudstone	Nangoh Lungpatau Buran Lunparai
Calcic Luvisol	Limestone	Semporna
Ferric Luvisol	Alluvium derived from basic and ultrabasic rocks Basic igneous rocks Mudstone	Pantagaluang Besar Lumerau
Chromic Luvisol	Alluvium derived from basic and ultrabasic rocks Calcareous alluvium Alluvium Ultrabasic igneous rocks Basic igneous rocks Tuffaceous rocks Limestone	Mangkap Terang Sabor Malawali Beeston Libong Tegupi
Orthic Luvisol	Alluvium derived from basic and ultrabasic rocks Alluvium Ultrabasic igneous rocks Basic igneous rocks Tuffaceous rocks Mudstone	Numatoi Darau Tingkayu Kobovan Talid Lumpongon
Gleyic Cambisol	Alluvium derived from basic and ultrabasic rocks Alluvium	Sinsulod Luba
Calcic Cambisol	Limestone	Madai
Humic Cambisol	Acid igneous rocks	Mantaki
Chromic Cambisol	Alluvium Ultrabasic igneous rocks Basic and intermediate igneous rocks Acid igneous rocks Chert Sandstone and mudstone	Mankawagu Silad Kawa Sadok Juak Luasong
Dystric Cambisol	Alluvium Ultrabasic igneous rocks Basic igneous rocks Tuffaceous rocks Chert Sandstone and mudstone Sandstone	Kelawat Meliau Nerelud Tenggara Durikong Laab Antulai
Eutric Cambisol	Alluvium Ultrabasic igneous rocks Basic and intermediate igneous rocks Acid igneous rocks Tuffaceous rocks	Bulanat Binuang Bombalai Quarry Hatton
Albic Arenosol	Alluvium	Serai
Cambic Arenosol	Alluvium Calcareous alluvium Sandstone	Kabili Pisau Pangarangan

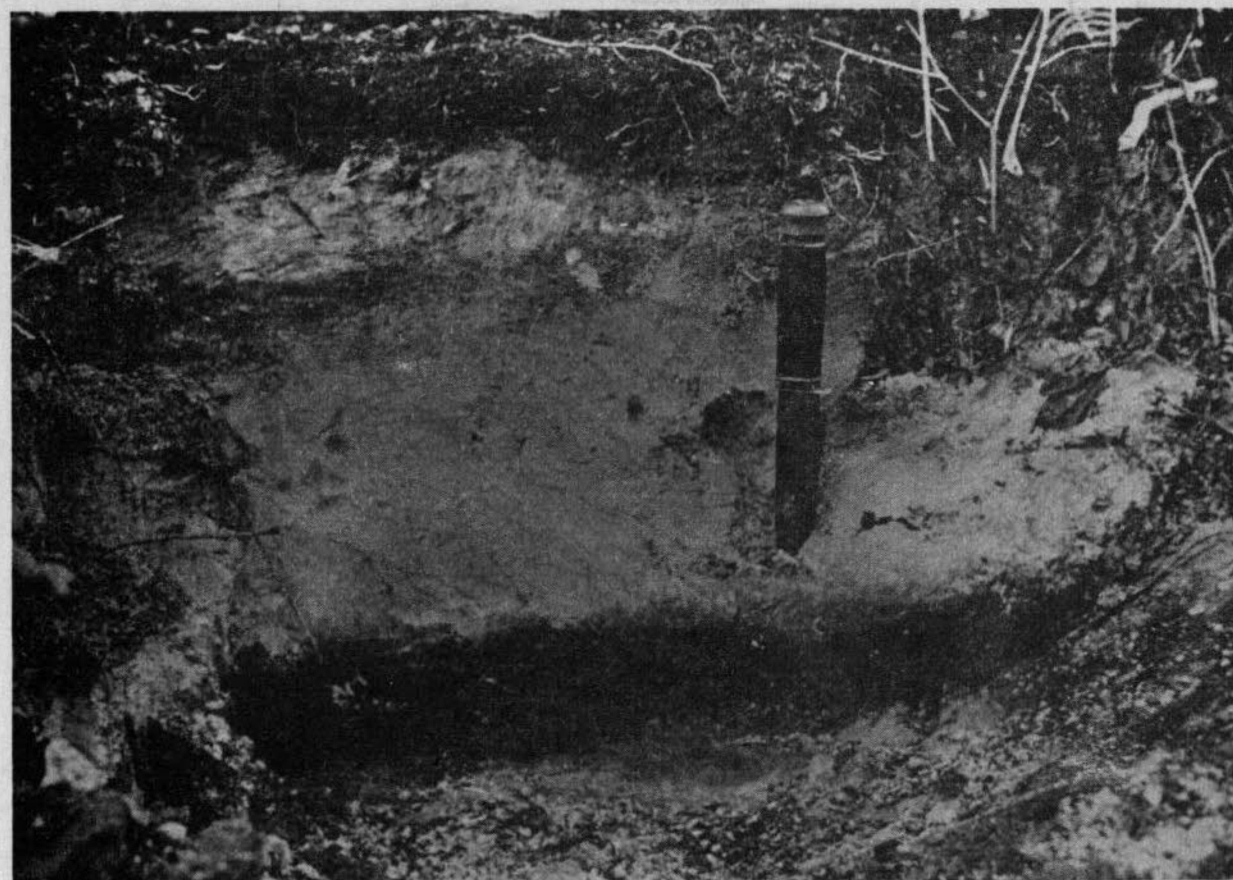


PLATE 1-1 Gleyic Podzol on sandstone (Pa Sia Family) at Mekhara, Sandakan. The spodic horizon rests directly on sandstone

PLATE 1-2 Orthic Podzol on pebble deposit (Silimpopon Family) at Sandakan

PLATE 1-3 Dystric Cambisol on 'Crab mound' of alluvium (Kelawat Family) in coastal swamp on Pulau Sebatik

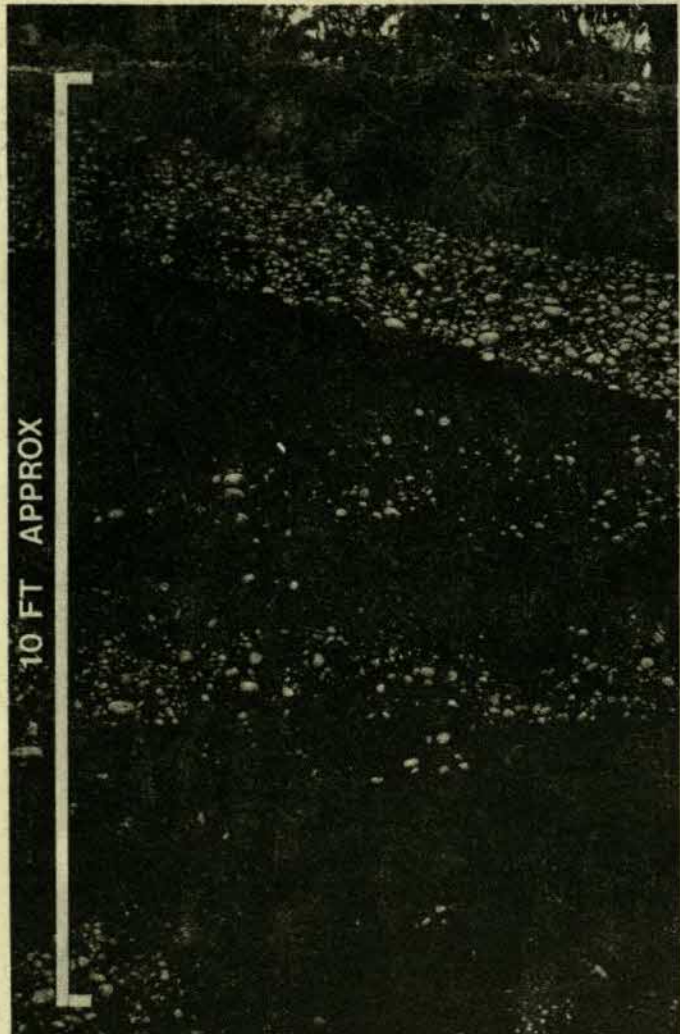


PLATE 1-4 Orthic Acrisol on mudstone with quartzite stonelines (Kumansi Family) at Sandakan

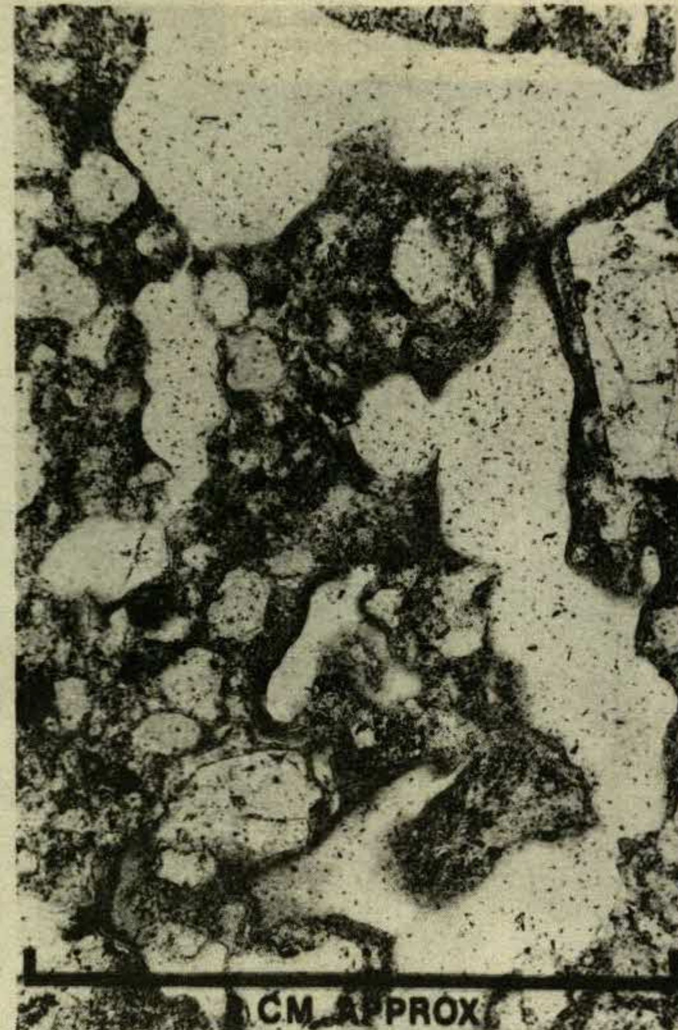


PLATE 1-5 Clay cutans (much magnified) in argillic horizon of Orthic Acrisol on alluvium (Paliu Family)

PLATE 1-6 Orthic Acrisol (Tanjong Lipat Family) on sandstone and mudstone at Kiansom. The argillic horizon is deep and stoneless.

PLATE 1-7 Orthic Acrisol (Tanjong Lipat Family) on sandstone and mudstone at Kiansom. The argillic horizon is deep and stony.

PLATE 1-8 Orthic Acrisol (Kumansi Family) on mudstone at Lungmanis. The argillic horizon is deep, yellowish brown and stony.

PLATE 1-9 Orthic Acrisol (Kumansi Family) on mudstone at Kiansom. The argillic horizon is deep, reddish brown and stony.

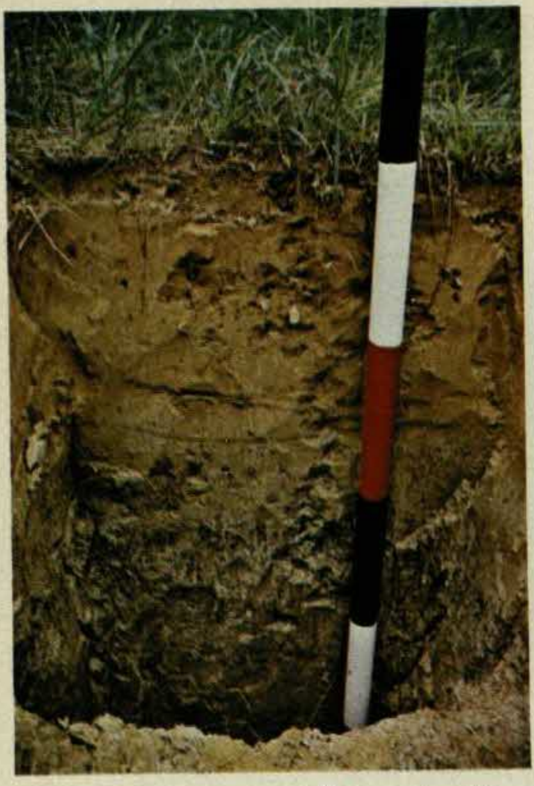


PLATE 1-10 Gleyic Acrisol (Inanam Family) on medium-textured alluvium at Tuaran. The gleying is caused by fluctuations of groundwater.

PLATE 1-11 Gleyic Acrisol (Gunong Alab Family) on sandstone and mudstone at 6 000 ft. a.s.l. on Gunong Kinabalu. Gleying results from continual wetness and the presence of a histic horizon.

PLATE 1-12 Orthic Acrisol (Paliu Family) on alluvium at Sook.

PLATE 1-13 Humic Gleysol (Guan Family) on fine-textured alluvium at Sook. Gleying is caused by the fluctuations of groundwater.

PLATE 1-14 Xanthic Ferralsol (Tungau Family) on alluvium at Poring. The oxic horizon is yellowish brown and moderately fine-textured.

PLATE 1-15 Rhodic Ferralsol (Pinianakan Family) on ultrabasic igneous rocks at Ranau. The oxic horizon is reddish brown and fine-textured.

PLATE 1-16 Humic Podzol (Karamatoi Family) on alluvium at Ulu Sipitang.

PLATE 1-17 Gleyic Podzol (Baiayo Family) on alluvium at Ranau. The albic horizon is compact and water perches above it periodically.

Histosols

GENERAL DESCRIPTION

Definition: Histosols are soils which have an organic O horizon of 40 cm (16 in) or more (60 cm (24 in) or more if the organic material consists mainly of sphagnum or moss or has a bulk density of less than 0.1). This horizon may extend continuously from the surface or represent the cumulative depth of the organic layers within the upper 80 cm (32 in) of the soil; the thickness of the O horizon may be less when it rests on rocks or on fragmental material of which the interstices are filled with organic matter.

Histosols form on peat which accumulates as a result of the slow decomposition of organic matter. This is associated with continuously high groundwater tables at any altitude or with relatively low temperatures, continuously moist conditions and nutrient-deficient rocks or regolith mainly at high altitudes. The presence of 'groundwater' as distinct from 'surface water' is therefore taken as the initial factor in the separation of the two soil units which occur in Sabah, namely Dystric and Eutric Histosols (Figure 1-1 and Table 1-2). Consistent information on the botanical composition and degree of decomposition of the peat deposits is lacking but it is recognised that when more information becomes available the soil families will probably be redefined.

TABLE 1-2 Histosols: soil families and associations in which they commonly occur

Soil unit	Parent material	Family	Association
Dystric Histosol	Peat	Klias	Klias Sapi Sipitang
		Kaintano	Maliau Serudong Kinabalu Trusmadi Tawai
	Sulphidic peat	Arang	Weston
Eutric Histosol	Calcareous peat	Mengalum	Usukan

DYSTRIC HISTOSOLS

Definition: Dystric Histosols have a pH (H_2O 1:1) of less than 5.5 at least in some part of the soil between 20 and 50 cm (8 and 20 in) of the surface.

They are formed on peat (Klias and Kaintano Families)and sulphidic peat (Arang Family). Sulphidic peat contains 0.75% or more sulphur (dry weight), mostly in the form of sulphides and has less than 3 times as much carbonate ($CaCO_3$ equivalent) as sulphur (USDA, 1973).

Klias Family

The Klias Family comprises Dystric Histosols which are formed on peat in swamps with very poor drainage conditions due to continuously high groundwater. The family is further separated on the presence or absence of mineral sediments. Where such sediments occur within peat they are further subdivided on the basis of their thickness and texture. Thick (>30 cm 12 in) and thin (5-30 cm 2-12 in) fine-textured sediments have been described. Profiles are finally separated on the presence of surface sediments (Profiles Od 1 and 2).

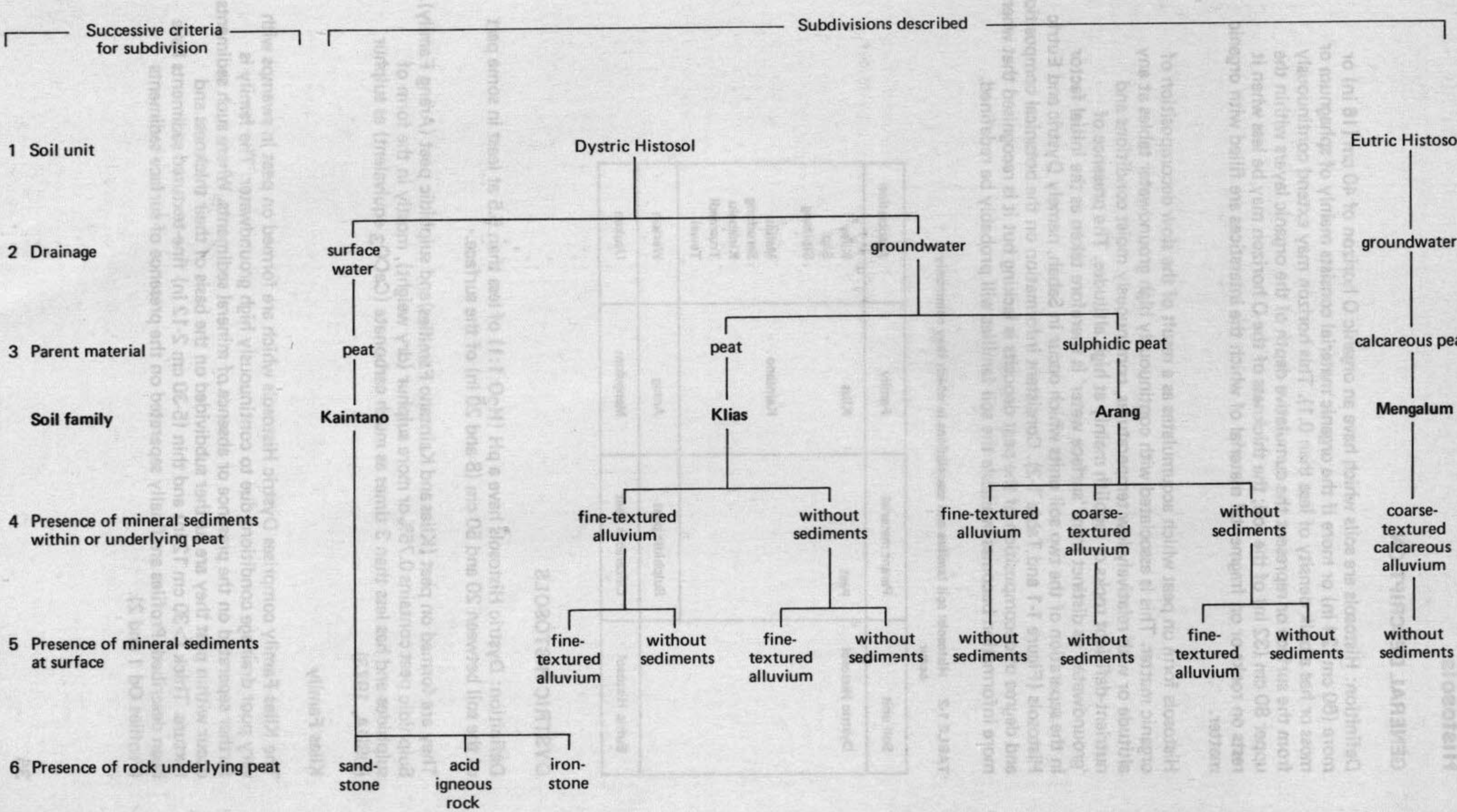


FIGURE 1-1 Histosols: criteria for subdivision and subdivisions described

These soils are generally highly acid with pH values of 4.5 and less. Cation exchange capacities are usually greater than 50 meq% due to high organic matter contents. Exchangeable cation levels are often very low but easily soluble phosphorus values are high due to high organic matter levels.

Kaintano Family

The Kaintano Family comprises Dystric Histosols which are formed mainly at high altitudes under continuously moist conditions. The soils are subdivided initially on the presence or absence of regolith or rock with 125 cm (50 in) of the surface. Soils which have been described on sandstone, ironstone and acid igneous rocks are subdivided on the degree of profile development in the regolith. Profiles on sandstone, for example, have been described with rock and with gleyic horizons underlying peat. Soils showing strong affinities to Placic and Gleyic Podzols with both gleyic and spodic horizons in sandstone regolith underlying peat also occur. The assessment of drainage conditions in the Kaintano Family is subjective; it appears to reflect the depth of peat, with more poorly drained profiles occurring on the deeper peat deposits (Profile Od 3).

Arang Family

The Arang Family comprises Dystric Histosols which are formed on sulphidic peat occurring in tidal swamps. The peat often contains high percentage of mineral matter and may be overlain by mineral sediments. Profiles are all very poorly drained, due to high water tables and many are flooded by high tides. They all show thionic properties with pH values dropping to 2 or less following oxidation. Because they occur in tidal swamps most soils are both saline and have high values of exchangeable sodium. Non-saline soils are associated with reclamation areas which are no longer flooded by tidal water (Profiles Od 4 and 5).

Most horizons of the soils in the Arang family meet the requirements of thionic horizons as defined by FAO (Dudal, 1968) i.e. they contain sufficient sulphur to cause a fall in pH after oxidation to below 3.5. The horizons of many of the soils of the Klias and Kaintano Families also show similar pH falls although the sulphur contents rarely exceed 0.2% total sulphur. It is thought that the oxidation of any base-deficient peat by boiling with hydrogen peroxide will cause a pH fall, because organic acids will be formed, due to incomplete oxidation.

EUTRIC HISTOSOLS

Histosols which lack the characteristics of the other units are termed Eutric Histosols. They have only been described on calcareous peat (Mengalum Family).

Mengalum Family

The Mengalum Family occurs on calcareous peat in coastal swamps and the only profile available (Profile Oe 1) shows calcareous peat overlying calcareous sand. The soils are very poorly drained. They contain very high amounts of exchangeable calcium due to the presence of shell fragments and pH values are near neutral to alkaline.

Lithosols

Definition: Lithosols are soils which are limited in depth by continuous coherent and hard rock within 10 cm (4 in) of the surface.

Lithosols comprise shallow ochric A horizons with or without shallow C horizons of weathering rock overlying hard rock. They occur on steep, well to excessively drained slopes, in close association with rock outcrops. They can form on any rock type and are minor soil units in all associations with steep slopes. In the Kinabalu Association, for example Lithosols on acid igneous rocks are the dominant soils. Because of their limited extent few Lithosols have been described and sampled and no family separations have been made.

Fluvisols

GENERAL DESCRIPTION

Definition: Fluvisols are soils developed from 'recent alluvial deposits' having no diagnostic horizons or none other than (unless buried at more than 50 cm (20 in) of the surface) an ochric A horizon, an O horizon, a gleyic horizon or a thionic horizon. Recent alluvial deposits are defined on the basis of the following characteristics: irregular organic matter profile, and/or receiving fresh sediments at regular intervals, and/or showing fine stratification, and/or having a low degree of ripening (expressed in terms of N value. (Dudal, 1969).

The four groups of Fluvisols recognised by FAO, namely Thionic, Calcaric, Dystric and Eutric Fluvisols all occur in Sabah on the coasts and in river valleys which are subject to periodic flooding and additions of alluvium. They are separated into soil families on the basis of parent material, (Table 1-3) and are further subdivided according to texture of parent material, presence of strata of contrasting textures, drainage, salinity and alkalinity; alkaline soils with >15% saturation with sodium are described as sodic (Dudal, 1968) (Figures 1-2 and 1-3).

TABLE 1-3 Fluvisols: soil families and associations in which they commonly occur

Soil unit	Parent material	Family	Association
Thionic Fluvisol	Sulphidic alluvium	Weston	Weston
	Alluvium	Kalibong	Weston
Calcaric Fluvisol	Calcareous alluvium	Nunuyan	Weston Usukan
Dystric Fluvisol	Alluvium	Tenghilan	Tuaran Labau
Eutric Fluvisol	Alluvium	Pegalan	Tuaran Labau Karamuak Kinabatangan

THIONIC FLUVISOLS

Definition: Thionic Fluvisols are Fluvisols having a thionic horizon. They occur on sulphidic alluvium and alluvium (Weston and Kalibong families respectively) occurring in tidal swamps. They are all potential acid sulphate soils.

Weston Family

Thionic Fluvisols of the Weston Family occur on sulphidic alluvium in tidal swamps. The alluvium ranges from coarse to fine in texture and it may be underlain by peat. Profiles are all poorly or very poorly drained being subject to tidal flooding and the fluctuations of groundwater. Poorly drained profiles have C, Cg horizon sequences and very poorly drained profiles have Cg horizons only. Profiles range from being strongly saline to non-saline and both sodic and non-sodic examples have been described. (Profiles Jt 1, 2 and 3).

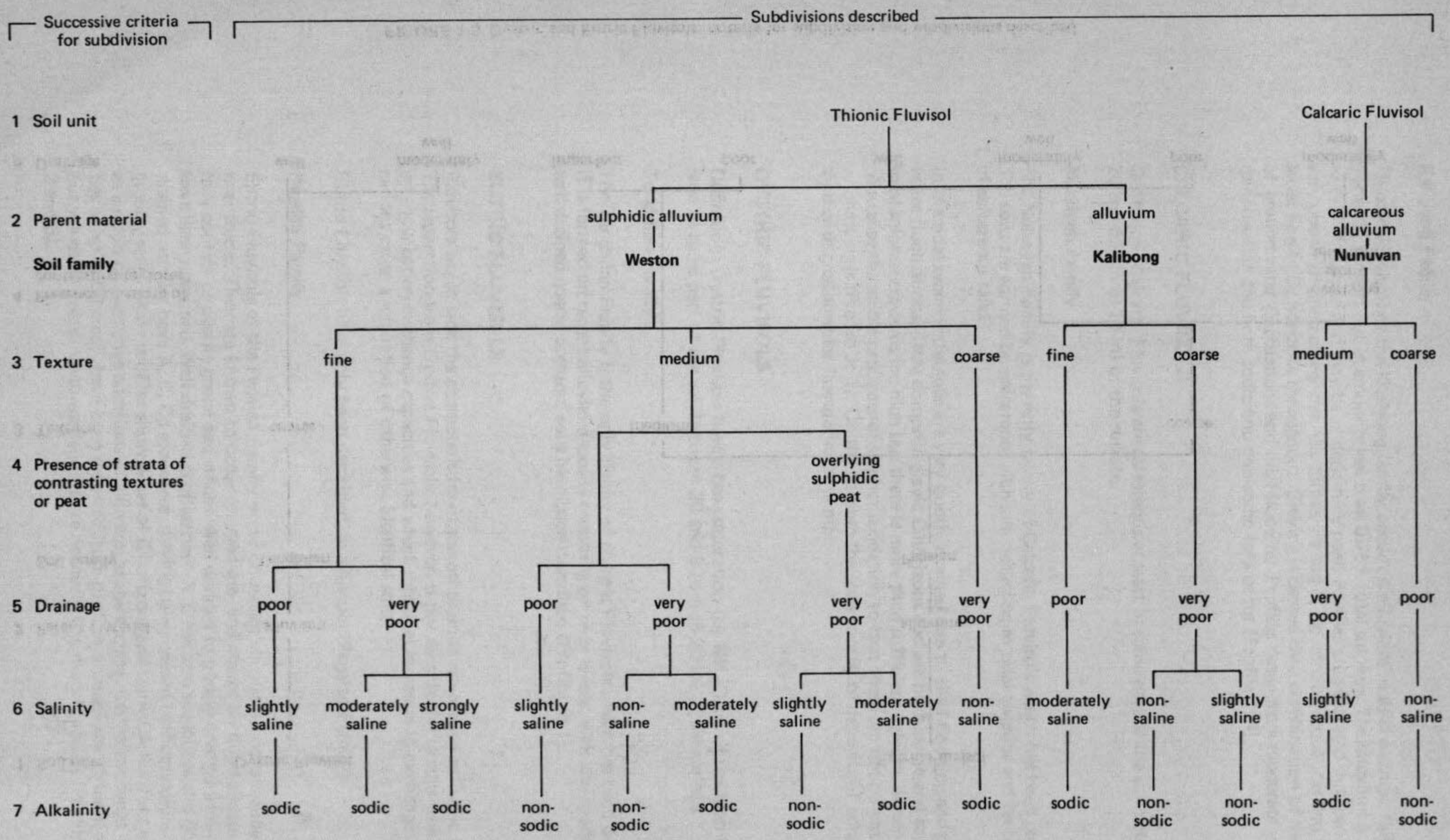


FIGURE 1-2 Thionic and Calcaric Fluvisols: criteria for subdivision and subdivisions described

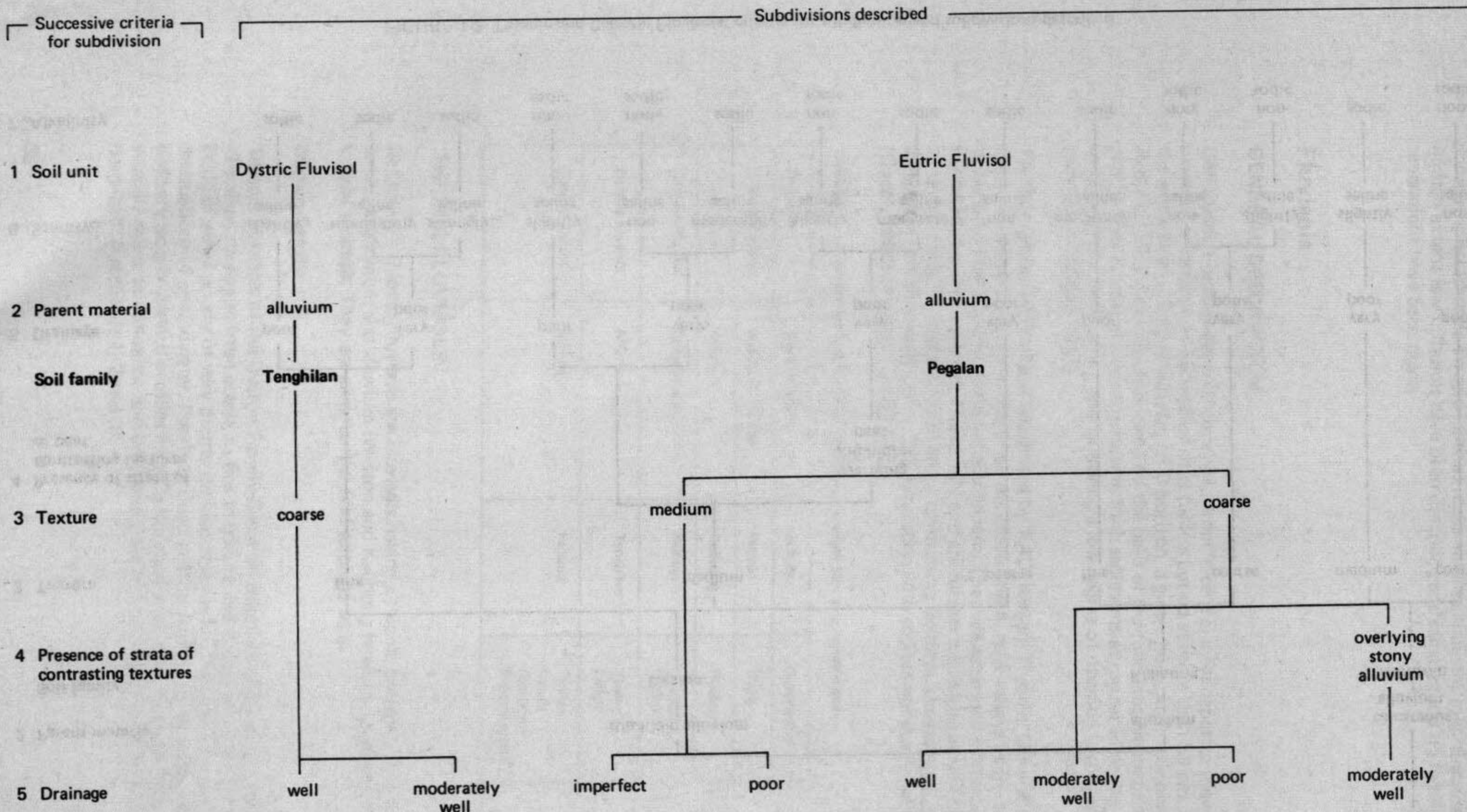


FIGURE 1-3 Dystric and Eutric Fluvisols: criteria for subdivision and subdivisions described

Kalibong Family

Thionic Fluvisols of the Kalibong family occur on alluvium in tidal swamps. Sulphur is normally present but in amounts less than 0.75% total sulphur. The alluvium is coarse to fine in texture and may be underlain by peat. Profiles are separated into poorly or very poorly drained categories, the former having C, Cg horizon sequences and the latter having Cg horizons throughout. Gleying is caused by a combination of the effects of groundwater fluctuations and tidal flooding. Profiles range from moderately saline to non-saline and both sodic and non-sodic soils occur (Profile Jt 4).

CALCARIC FLUVISOLS

Definition: Calcaric Fluvisols are calcareous at least in some part of the soil between 20 and 50 cm (8-20 in) of the surface.

Nunuyan Family

The Nunuyan Family is the only family of Calcaric Fluvisols which has been described. The soils are formed on calcareous alluvium occurring in tidal swamps and on beaches of calcareous sand.

In the tidal swamps the soils are very poorly drained due to tidal flooding and groundwater fluctuations. They comprise gleyic C horizons and are both saline and sodic. The total sulphur contents are high but there is more than sufficient calcium present to neutralise the acidic products of sulphur oxidation so that these are not potential acid sulphate soils (Profile Jc 1). On the beaches the soils consist of deposits of coralline sand with groundwater fluctuating at depth.

DYSTRIC FLUVISOLS

Definition: Dystric Fluvisols have a base saturation (by NH_4OAc) of less than 50% at least in some part of the soil between 20 and 50 cm (8-20 in) of the surface.

Tenghilan Family

The Tenghilan Family is the only family of Dystric Fluvisols which has been described. It is formed on recent alluvial deposits occurring on river levees. Well and moderately well drained coarse-textured soils have been described (Profile Jd 1).

EUTRIC FLUVISOLS

Fluvisols which lack the characteristics of the other units are classed as Eutric Fluvisols. The separation from Dystric Fluvisols, however, is not meaningful in soils which have very low cation exchange capacities and where marginal increases in exchangeable cations cause a separation of otherwise identical soils.

Eutric Fluvisols have only been described on alluvium (Pegalan Family).

Pegalan Family

Eutric Fluvisols of the Pegalan Family occur on recent alluvial deposits mainly on river levees. They are known to occur on medium- and coarse-textured alluvium which may contain or overlie gravel and stones. Well drained to poorly drained profiles have been described. Well drained profiles have A, C horizon sequences and poorly drained profiles have A, C, Cg sequences, gleying being caused by fluctuations of groundwater. Many profiles show series of C horizons and buried A horizons also occur as a result of successive additions of alluvium at the surface. Cation exchange capacities of up to 30 meq% have been reported from profiles on medium-textured alluvium but values on coarse textured deposits are normally less than 10 meq% (Profiles Je 1, 2 and 3).

Gleysols

GENERAL DESCRIPTION

Definition: Gleysols are soils having gleyic horizons with their upper boundaries within 50 cm (20 in) of the surface; having no other diagnostic horizons or none other than (unless buried at more than 50 cm (20 in) of the surface) an A horizon, an O horizon, a cambic B horizon, a calcic, gypsic or plinthic horizon.

Gleysols are essentially wet soils and are often saturated with water. They are mainly formed on alluvium where gleyic horizons result from the fluctuations of groundwater, but they also occur at high altitudes under continuously moist conditions, where gleying is caused by surface water effects. Humic, Calcaric, Dystric and Eutric Gleysols have been described in Sabah. They are subdivided into families on the basis of parent materials (Table 1-4) and the families are subdivided using certain of the following criteria (Figures 1-4 to 1-7):

1. Texture of gleyic horizon(s)
2. Presence of strata of contrasting textures
3. Drainage
   - i. surface water or groundwater effects
   - ii. category
   - iii. presence of Fe/Mn concretions
4. Alkalinity (< or >15% saturation with exchangeable Na)
5. Salinity
6. Depth

HUMIC GLEYSOLS

Definition: Humic Gleysols are Gleysols having an umbric A horizon, or an O horizon. They occur on calcareous and undifferentiated alluvium and on sandstone and acid igneous rocks at high altitudes. Thionic-humic Gleysols occur on sulphidic alluvium.

Berhala Family

The Berhala Family comprises soils formed on calcareous alluvium occurring in swamps. Coral, which is the source of calcium, probably underlies the alluvium, which itself contains coral fragments and is coarse textured. The soils are very poorly drained due to groundwater fluctuations, and are periodically flooded. They have O, Cg horizon sequences, the O horizon being histic. Soil pH values are near neutral (Profile Gh 7).

Guan Family

The Guan Family (Figure 1-4) comprises soils formed on fine- to coarse-textured alluvium which may be underlain by alluvia of contrasting textures, with or without stones or peat. The soils occur on floodplains, in infilled channels of meander belts, on the margins of peat swamps and also on old beaches and terraces. They are all subject to the fluctuations of groundwater and are very poorly drained. Profiles with iron and manganese concretions may occur. Soils with umbric A horizons have Ag, Cg sequences; those with histic horizons have O, Cg sequences.

In general the soils are strongly acid. Reported cation exchange capacities range from 15-60 meq % on fine-textured alluvium and in general are higher than those on coarse-textured deposits where reported values range from 1-27 meq %. The highest values occur in the histic horizons. Nutrient levels are similarly highest in the surface horizons with high organic matter contents. High values of exchangeable magnesium are normal in profiles on fine-textured alluvium. Base saturation values are variable. (Profiles Gh 1-4) (Plate 1-13)

TABLE 1-4 Gleysols: soil families and associations in which they commonly occur

Soil unit	Parent material	Family	Association
Humic Gleysol	Calcareous alluvium	Berhala	Usukan
	Alluvium	Guan	Sapi Klias Kinabatangan Tuaran Tanjong Aru Sook Sipitang
	Sandstone	Kidukarok	Maliau Trusmadi
	Acid igneous rocks	Wullersdorf	Wullersdorf
Thionic-humic Gleysol*	Sulphidic alluvium	Bergosong	Weston
Calcaric Gleysol	Calcareous alluvium	Lari	Weston
Dystric Gleysol	Alluvium	Koyah	Kinabatangan Tuaran Sapi Labau Binkor Brantian Kepayan Sinarun Dalit Tanjong Aru Sipitang
Thionic-dystric Gleysol*	Sulphidic alluvium	Metah	Weston
Eutric Gleysol	Alluvium	Bangawat	Kinabatangan Sapi Karamuak Labau Binkor Tanjong Aru
	Mudflows	Rasang	Kretam
Thionic-eutric Gleysol*	Alluvium	Libur	Weston

*In the Soil Map of the World, Gleysols with thionic horizons were classified with the Thionic Fluvisols, because it was felt that the thionic properties were much more important than the presence of incipient cambic or gleyic horizons. It has been agreed, however, that these soils may be kept as Gleysols recognising their thionic properties at the subunit level. Thionic-dystric and Thionic-eutric Gleysols are recognised in the same way. (Pécrot 1972).

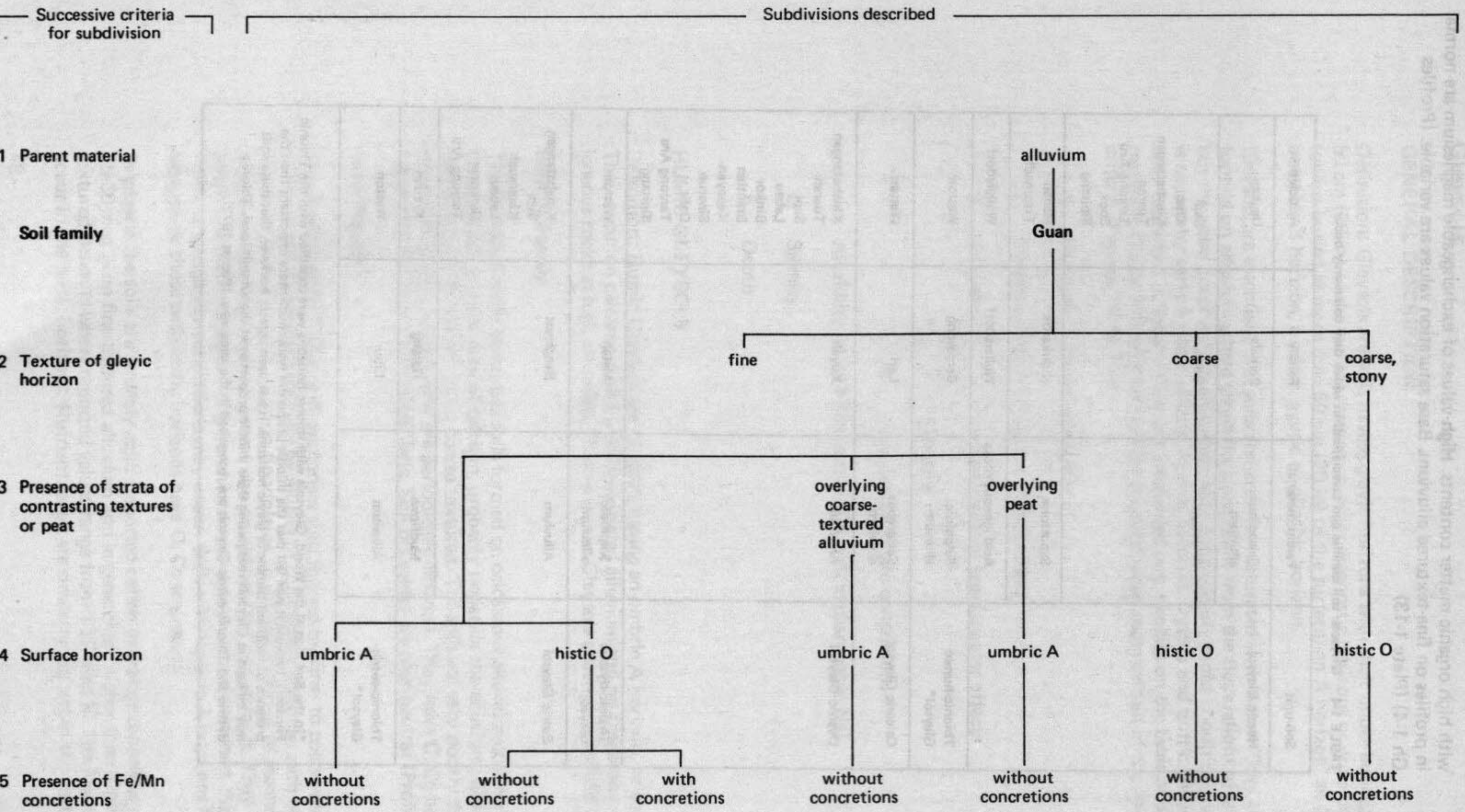


FIGURE 1-4 Humic Gleysols on alluvium: criteria for subdivision and subdivisions described

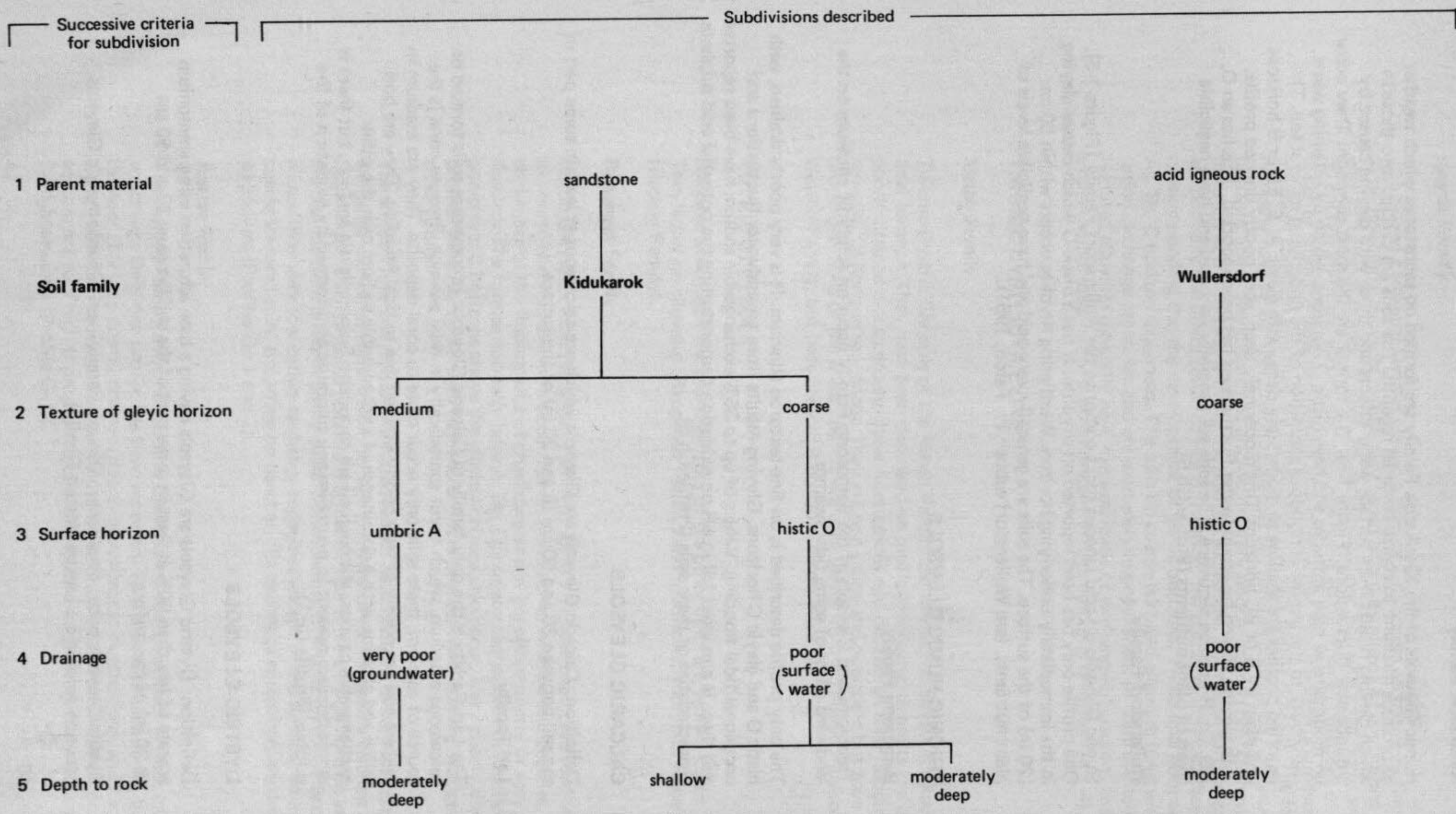


FIGURE 1-5 Humic Gleysols on sandstone and acid igneous rock: criteria for subdivision and subdivisions described

Kidukarok Family

Humic Gleysols of the Kidukarok Family are formed on sandstones which weather to produce medium- to coarse-textured regolith. The soils are divided into those in which gleying results from surface-water effects and those with gleying caused by groundwater fluctuations (Figure 1-5). The former are the most common. They occur on mountains at high altitudes and have histic O horizons, which by retaining water, contribute to the almost continuous saturation of the underlying mineral soil. The reported profiles are shallow to moderately deep, with gleyic A, E, EB or B horizons underlain by B or BC horizons. One moderately deep, very poorly drained profile, with gleying caused by groundwater fluctuations has been reported. This has an O, AG, Cg, R horizon sequence. The soils are generally very acid and have negligible levels of plant nutrients (Profile Gh 5).

Wullersdorf Family

Humic Gleysols on acid igneous rocks comprise the Wullersdorf Family (Figure 1-5). One profile only has been reported on rhyolite. It has a histic O which causes gleying in the immediately underlying horizon. Weathering rhyolite occurs within 50 cm (20 in) of the surface. The soils are generally very acid and have negligible levels of plant nutrients. (see Wullersdorf subfamily: Paton, 1961).

THIONIC-HUMIC GLEYSOLS

Bergosong Family

Thionic-humic Gleysols of the Bergosong Family occur on sulphidic alluvium on the landward edges of some tidal swamps.

The only profile described is on fine-textured alluvium. It is very poorly drained, with histic O and gleyic C horizons. Gleying results from groundwater fluctuations and occasional tidal flooding. Values of up to 35% exchangeable sodium have been reported and there is a marked fall in pH on oxidation demonstrating the potential acid sulphate characteristics of these soils (Profile Gh 6).

CALCARIC GLEYSOLS

Definition: Calcaric Gleysols are Gleysols which are calcareous at least in some part of the soil between 20 and 50 cm (8 and 20 in) of the surface.

Lari Family

The Lari Family is the only family of Calcaric Gleysols. It comprises soils formed on calcareous alluvium, which occur sporadically in tidal swamps. Because coral is the source of calcium, these soils only occur close to coral deposits. They are medium in texture and are poorly or very poorly drained due to tidal flooding. They are both saline and alkaline with a dominance of exchangeable sodium over the other exchangeable cations, although all are abundant. Sulphur levels are high, but there is ample calcium present to neutralise any sulphuric acid formed by oxidation of the sulphur (Profile Gc 1).

DYSTRIC GLEYSOLS

Definition: Dystric Gleysols are Gleysols having a base saturation using ammonium acetate of less than 50% at least in some part of the soil between 20 and 50 cm (8-20 in) of the surface.

Dystric Gleysols occur on alluvium (Koyah Family) and Thionic-dystric Gleysols occur on sulphidic alluvium (Metah Family).

Koyah Family

The Koyah Family of Dystric Gleysols (Figure 1-6) occurs on coarse-to fine-textured, sometime stony alluvium, which may be underlain by alluvia of contrasting textures, with or without stones, or peat. By definition gleyic horizons must occur within 50 cm (20 in) of the surface and they can result either from fluctuations of ground–water or from the slow percolation of surface water. Profiles with groundwater gleying are more common and they are either poorly or very poorly drained. The former normally have A, Bg, Cg horizon sequences but profiles containing non-gleyic B horizons above gleyic horizons also occur. Very poorly drained profiles have gleyic horizons at the surface with Ag, Cg horizon sequences. Soils with surface water gleying are normally the direct result of rice cultivation; the puddling of the surface soil causing ponding and the development of gleyic horizons. These soils normally have Ag, Bg, C horizon sequences. The soils on coarse-textured alluvium have very low cation exchange capacities and are extremely impoverished. In contrast, soils on fine-textured alluvium generally have medium levels of exchangeable cations and exchangeable magnesium is often present in high amounts (Profiles Gd 1-4).

THIONIC-DYSTRIC GLEYSOLS

Metah Family

Thionic-Dystric Gleysols of the Metah Family are formed on sulphidic alluvium in tidal swamps. They have been described on medium-textured deposits and are all poorly drained due to groundwater fluctuations and occasional tidal flooding. They have Bg, Cg horizon sequences. They are non-saline and non-sodic but have thionic properties. Soils of the Metah family are very similar to the Thionic Fluvisols of the Weston Family, but have cambic B horizons (Profile Gd 5).

EUTRIC GLEYSOLS

Gleysols which lack the characteristics of the other units are termed Eutric Gleysols. They accur on alluvium (Bangawat Family) and mudflows from mud volcanoes (Rasang Family).

Bangawat Family

Eutric Gleysols of the Bangawat Family (Figure 1-7) have been described on fine- to course-textured alluvium occurring on floodplains, swamps and beaches. They are all subject to the fluctuations of groundwater and are either poorly or very poorly drained. The former normally have A, Bg, Cg horizon sequences but profiles with non-gleyic B horizons above the gleyic horizons also occur. Very poorly drained profiles have Ag, Cg horizon sequences. Some profiles have iron and manganese concretions.

The soils on fine- and medium-textured alluvia have medium to very low cation exchange capacities and medium to high contents of exchangeable calcium and magnesium. Exchangeable potassium is low except in the surface horizon where there are also medium levels of easily soluble phosphorus. The soils on coarse-textured alluvia have very low cation exchange capacities except in the surface horizons. In coarse-textured soils, occurring on beaches, the exchange complexes are dominated by sodium (Profiles Ge 1 and 2).

Rasang Family

The Rasang Family comprises Eutric Gleysols on mudflows issuing from mud volcanoes. Only one profile has been reported. This is on a fine-textured, but stony deposit. It is very poorly drained, due to groundwater fluctuations, and has an Ag, Bg, Cg horizon sequence. Soil pH values are strongly alkaline. Values of exchangeable sodium are very high throughout and exchangeable magnesium and calcium are present in high amounts (Profile Ge 3).

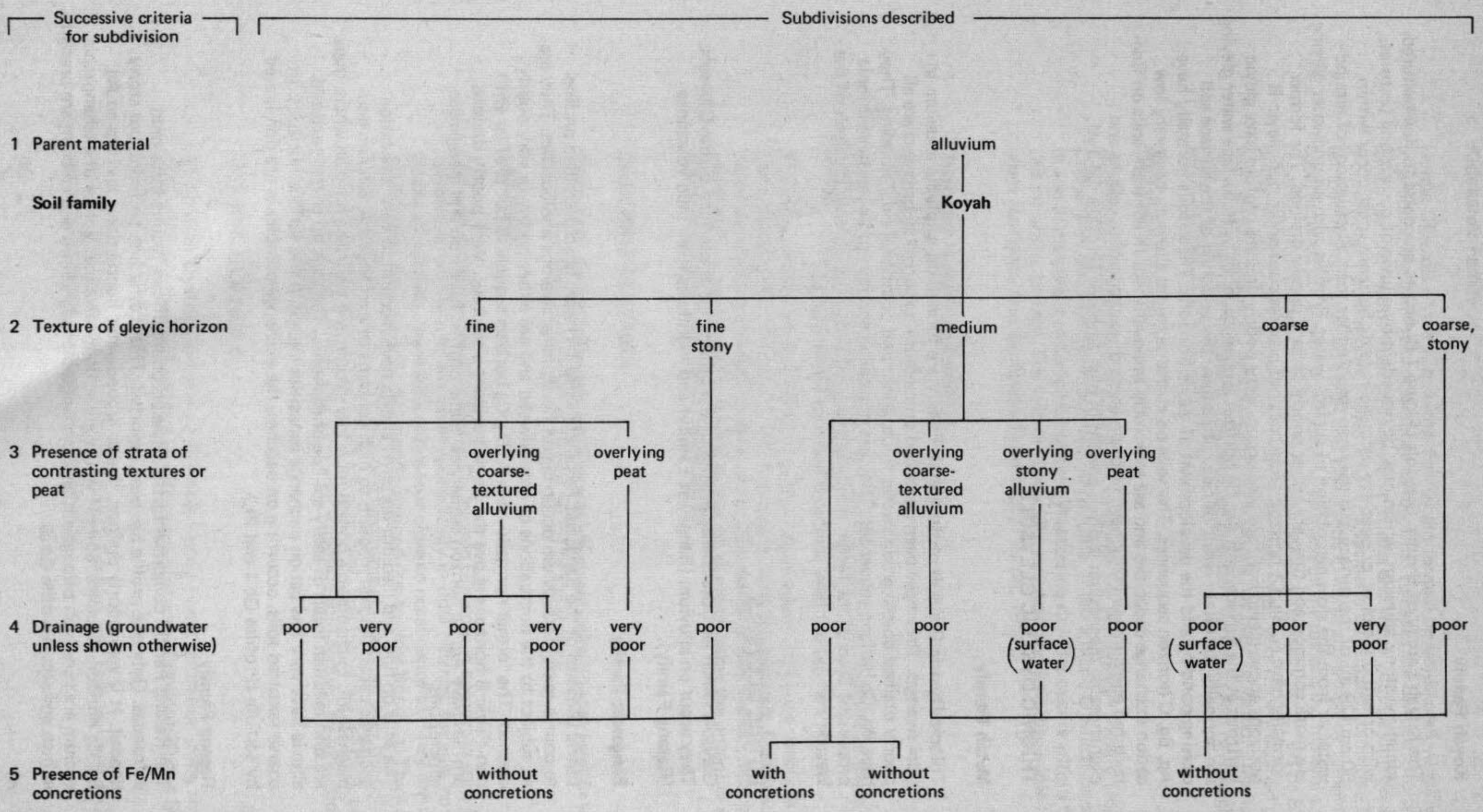


FIGURE 1-6 Dystric Gleysols on alluvium: criteria for subdivision and subdivisions described

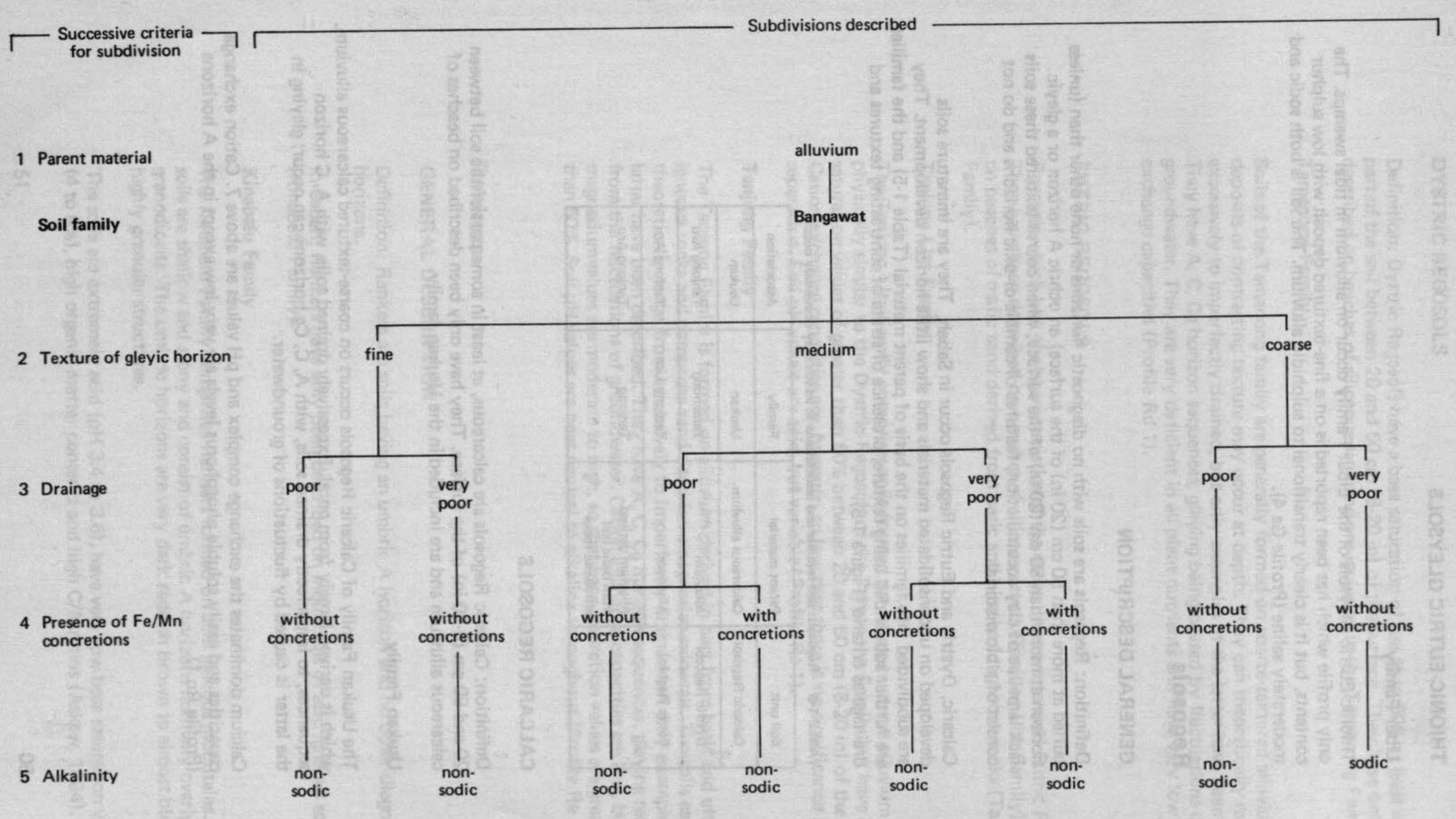


FIGURE 1-7 Eutric Gleysols on alluvium: criteria for subdivision and subdivisions described

THIONIC-EUTRIC GLEYSOLS

Libur Family

Thionic-Eutric Gleysols of the Libur Family occur on alluvium in tidal swamps. The only profile which has been reported is on a fine-textured deposit with low sulphur contents, but it is clearly transitional to sulphidic alluvium. The soil is both sodic and moderately saline (Profile Ge 4).

Regosols

GENERAL DESCRIPTION

Definition: Regosols are soils with no diagnostic horizons or none other than (unless buried at more than 50 cm (20 in) of the surface) an ochric A horizon or a gleyic horizon at more than 50 cm (20 in) of the surface; when coarse-textured these soils lack lamellae of clay accumulation, features of cambic or oxic horizons and do not consist of albic material.

Calcaric, Dystric and Eutric Regosols occur in Sabah. They are immature soils developed on unconsolidated materials and show little horizon development. They are subdivided into families on the basis of parent material (Table 1-5) and the families are further subdivided using texture, presence of strata of contrasting textures and drainage as criteria (Figure 1-8).

TABLE 1-5 Regosols: soil families and associations in which they commonly occur

Soil unit	Parent material	Family	Association
Calcaric Regosol	Calcareous alluvium	Usukan	Usukan
Dystric Regosol	Alluvium	Tamanong	Tanjong Aru
Eutric Regosol	Alluvium	Tanjong Lita	Tanjong Aru
	Alluvium derived from basic and ultrabasic rocks	Tanjong	Tanjong Aru

CALCARIC REGOSOLS

Definition: Calcaric Regosols are calcareous, at least in some part of the soil between 20 and 50 cm (8-20 in) of the surface. They have only been described on beaches of calcareous alluvium and are included in the Usukan family.

Usukan Family

The Usukan Family of Calcaric Regosols occurs on coarse-textured calcareous alluvium, which is derived largely from coral. Excessively drained soils, with A, C horizon sequences, to imperfectly drained soils, with A, C, Cg horizons can occur; gleying in the latter is caused by fluctuations of groundwater.

Calcium dominates the exchange complex and pH values are above 7. Cation exchange capacities and easily soluble phosphorus levels are very low except in the A horizons (Profile Rc 1).

DYSTRIC REGOSOLS

Definition: Dystric Regosols have a base saturation of less than 50% at least in some part of the soil between 20 and 50 cm (8-20 in) of the surface. They have only been described on beaches of siliceous sand and are included in the Tamanong Family.

Tamanong Family

Soils of the Tamanong family are generally formed on coarse-textured alluvium, but deposits of contrasting texture may occur at depth. They can theoretically range from excessively to imperfectly drained, but only examples of the latter have been described. They have A, C, Cg horizon sequences, gleying being caused by fluctuations of groundwater. They are very deficient in all plant nutrients and have very low cation exchange capacities (Profile Rd 1).

EUTRIC REGOSOLS

Regosols which lack the characteristics of the other units are termed Eutric Regosols. They have been described on beaches of siliceous sand (Tanjong Lita Family), and on beaches of mafic sand derived from basic and ultrabasic igneous rocks (Tanjong Family).

Tanjong Lita Family

The Tanjong Lita Family comprises soils formed on coarse-textured alluvium. They are physically similar to the Dystric Regosols of the Tamanong Family but have base saturation values of greater than 50% between 20 and 50 cm (8-20 in) of the surface. Cation exchange capacities are, however, so low that there is no significance in this separation. Soil pH values are acid, but variable (Profile Re 1).

Tanjong Family

The Tanjong Family is formed on alluvium derived in part from basic and ultrabasic igneous rocks and comprises sand-sized ferromagnesian minerals. The soils can theoretically range from excessively to imperfectly drained but only examples of the latter have been described. They have A, C, Cg horizon sequences, gleying resulting from the fluctuations of groundwater. Cation exchange capacities are low, but magnesium values are moderate to high, so that base saturation values are greater than 50%. Soil pH values are near neutral to alkaline throughout (Profile Re 2).

Rankers

GENERAL DESCRIPTION

Definition: Rankers are soils having an umbric A horizon and no other diagnostic horizons.

In Sabah, Rankers have only been described on mountains of acid igneous rocks (Kinabalu Family).

Kinabalu Family

The Kinabalu Family comprises Rankers formed on acid igneous mountains. The soils are shallow and stony and consist of umbric A horizons normally overlying granodiorite. The umbric horizons are very dark reddish brown to almost black with highly granular structures.

The soils are extremely acid (pH 3.4 to 3.6), have very low base saturation values (4 to 8%), high organic matter contents and high C/N ratios (Askew, 1964).

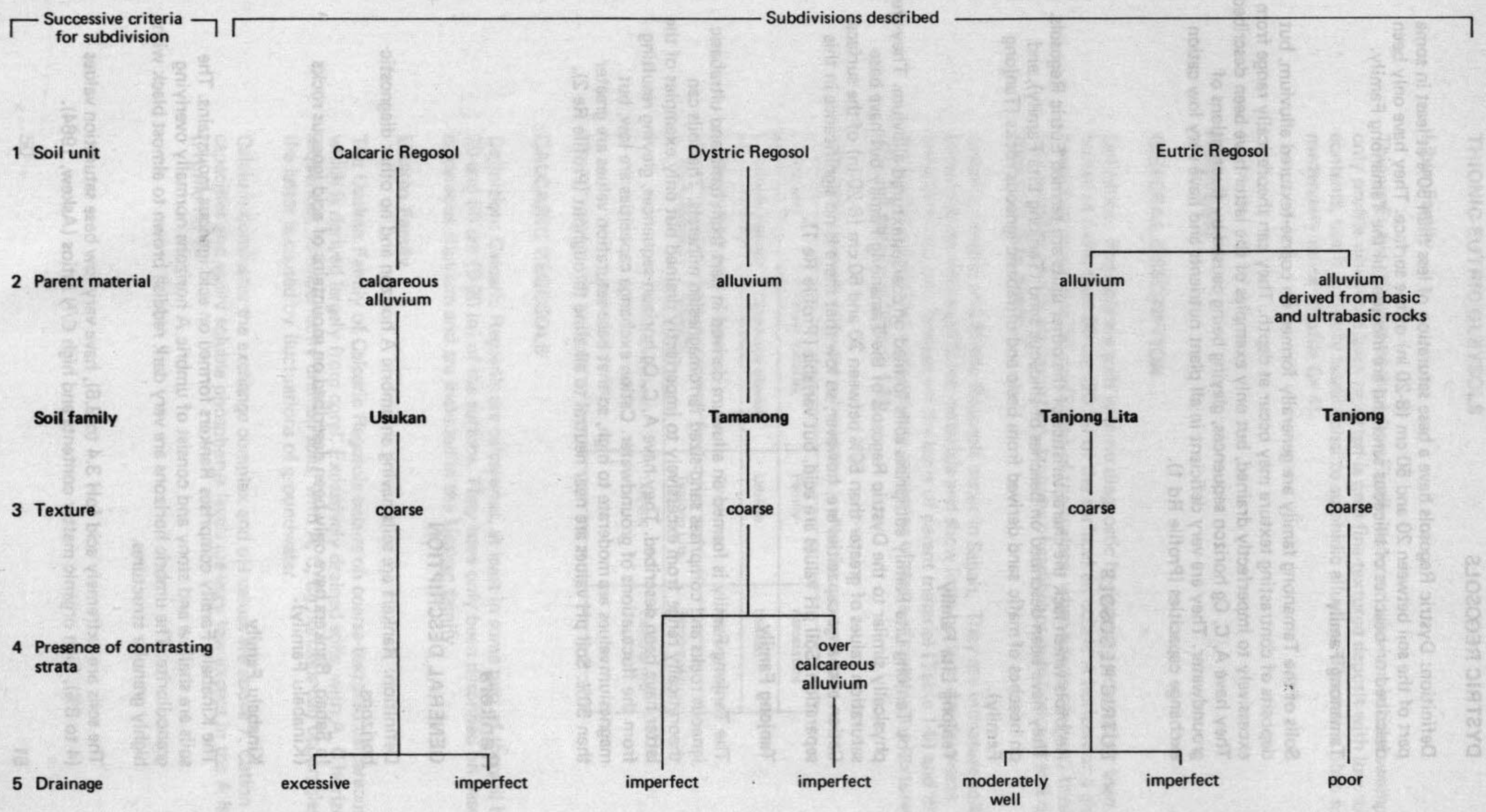


FIGURE 1-8 Calcaric, Dystric and Eutric Regosols: criteria for subdivision and subdivisions described

Podzols

GENERAL DESCRIPTION

Definition: Podsols are soils having a spodic B horizon. In addition to spodic horizons, Podzols normally have albic E horizons. They are formed typically on base-deficient, often highly siliceous parent materials and the albic horizons usually contain only silica and a few other resistant minerals such as zircon and anatase. Most of the iron and aluminium from the eluvial horizons has been removed and either deposited with organic carbon in the spodic B horizon or lost in the drainage water. Spodic horizons are often indurated giving rise to perched water tables and gleyic horizons. Podzols have affinities with Acrisols and this is sometimes shown by an argillic horizon occurring below the spodic horizon. Some Podzols with deep albic E horizons are similar to Albic Arenosols, and those with spodic horizons below 125 cm (50 in) are included in that soil unit.

Placic, Gleyic, Humic and Orthic Podzols have been described in Sabah. They have been divided into families (Table 1-6) and lower categories using the following criteria where defined:

1. Parent material
2. Profile drainage, including category and whether affected by groundwater or surface water
3. Texture of the spodic horizon
4. Presence or absence of an indurated spodic horizon
5. Presence or absence of a compact E horizon
6. Depth

TABLE 1-6 Podzols: soil families and the associations in which they commonly occur

Soil unit	Parent material	Family	Association
Placic Podzol	Acid igneous rocks	Mesilau	Kinabalu
Gleyic Podzol	Alluvium	Baiayo	Tanjong Aru Sipitang Sook Kepayan Brantian Pinosuk
	Sandstone and mudstone	Pa Sia	Maliau Serudong Trusmadi
Humic Podzol	Alluvium	Karamatoi	Tanjong Aru Kepayan Brantian
Orthic Podzol	Alluvium	Silimpopon	Tanjong Aru Kepayan Brantian
	Sandstone	Sibuga	Serudong Maliau

PLACIC PODZOLS

Definition: Placic Podzols have a thin iron pan in or over the spodic B horizon. They have only been described on acid igneous rocks. (Mesilau Family).

Mesilau Family

Placic Podzols of the Mesilau Family occur on granodiorite on Gunong Kinabalu. They consist of umbric A horizons with granular structures overlying iron pans, which in turn overlie brown weathering horizons. Sometimes there is a small amount of pale coloured material above the iron pan. These soils show no signs of mottling or poor drainage below the iron pan (Askew, 1964).

GLEYIC PODZOLS

Definition: Gleyic Podzols have a gleyic horizon, or show features which indicate saturation with water at some period of the year.

The Gleyic Podzols described in Sabah are all either imperfectly or poorly drained and have O or A, albic or gleyic E, spodic B and BC or gleyic BC horizon sequences. Two families of Gleyic Podzols have been recognised, namely the Baiayo Family on alluvium and the Pa Sia Family on sandstone and mudstone.

Baiayo Family

Soils of the Baiayo Family (Figure 1-9) are formed on alluvia which can range from coarse-textured and highly siliceous beach sands to moderately fine-textured terrace deposits. Sequential deposition is a common feature with coarse-textured alluvia usually overlying finer-textured alluvia. Quartzite pebbles occur in some profiles. The spodic horizons are normally coarse- or moderately coarse-textured. The soils include those which show surface water gleying only and those that have drainage imperfections due to groundwater effects and possibly surface imperfections as well. Most of the described profiles are classed as imperfectly drained with about 25% having impeded drainage due entirely to surface water effects. Imperfect drainage due to surface water is nearly always associated with either an indurated spodic B, a compacted albic E horizon or both. Profiles with fluctuating groundwater tables are either imperfectly or poorly drained; the former have gley mottled horizons and the latter have gleyic horizons below the spodic horizon. The spodic horizons are frequently indurated or contain concretions; compacted albic horizons are less common.

Soils of the Baiayo Family are very deficient in bases with pH values mostly below 5. Cation exchange capacities range widely; the O horizon if present has values of from 5 to more than 100 meq%, the E horizon has values mostly less than 1.0 meq% and the spodic horizon has values mainly between 5 and 15 meq%. These very low values are accompanied by generally low levels of exchangeable cations, except in some of the surface O horizons. Base saturation figures are mostly low. Quartz is the dominant mineral of the clay size fraction and in the upper horizons it is often the only detectable mineral. In the spodic horizon small amounts of kaolinite and more rarely vermiculite and illite have been found. Iron and aluminium levels generally show an appreciable increase in the spodic horizons relative to the horizons above (Profiles Pg 1-3) (Plate 1-17).

Pa Sia Family

The Pa Sia Family of Gleyic Podzols (Figure 1-10) is formed on sandstone and mudstone, particularly on the moderate dipslopes of sandstone cuestas, at a range of altitudes, but notably above about 600 m (2 000 ft) a.s.l. The soils are imperfectly to poorly drained due mainly to surface water effects. They normally have albic E horizons, which are also, in part, gleyic. Soils with drainage imperfections resulting from groundwater fluctuations have gleyic horizons below the spodic horizons.

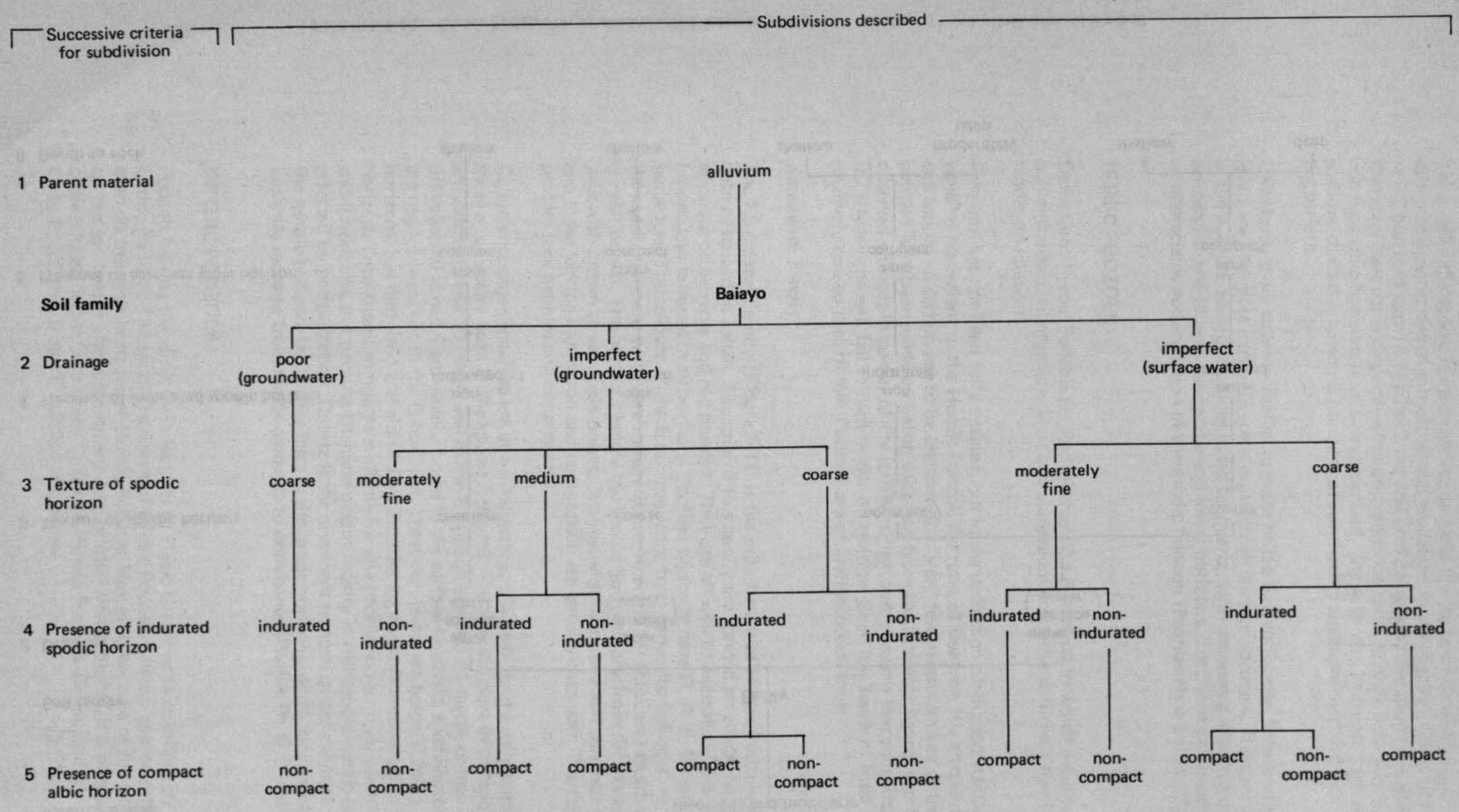


FIGURE 1-9 Gleyic Podzols on alluvium: criteria for subdivision and subdivisions described

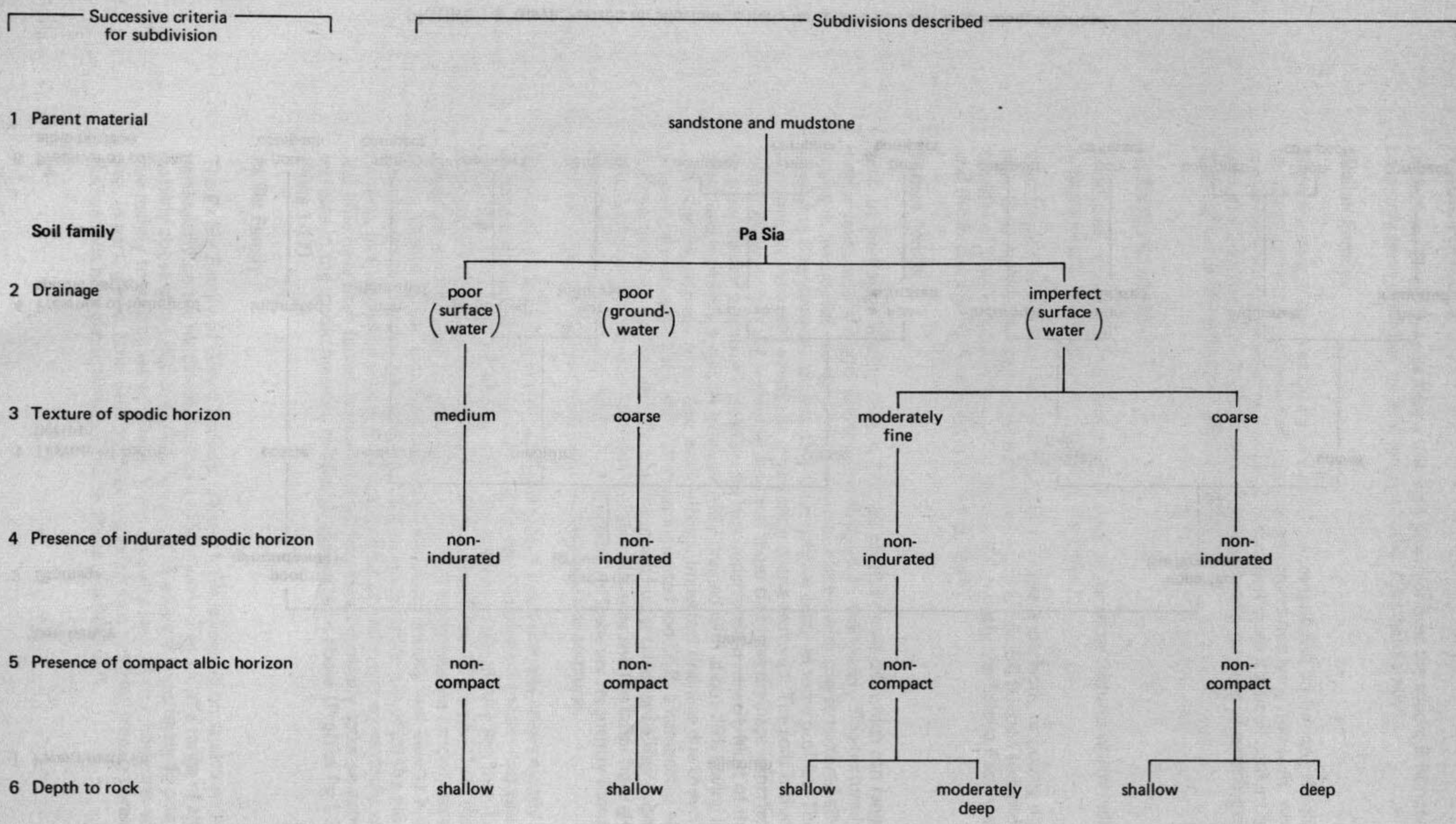


FIGURE 1-10 Gleyic Podzols on sandstone and mudstone: criteria for subdivision and subdivisions described

Textures of the spodic horizon are moderately fine to coarse and probably reflect the different proportions of sandstone and mudstone in the regolith. Some of the lower B or BC horizons may be fine textured and broken cutans have been described suggesting that they have some characteristics of argillic horizons. Neither indurated spodic nor compact albic horizons have been described. The soils vary in depth from deep to shallow, the latter having C horizons of weathering sandstone within 50 cm (20 in) of the surface.

Chemically these soils are similar to those of the Baiayo Family. Exchangeable cation levels are negligible except in some organic rich surface horizons. The clay size fraction in the A and E horizons is dominated by quartz, with increasing amounts of kaolinite, vermiculite and illite in the spodic and lower horizons. Total iron and aluminium show an appreciable accumulation in the spodic horizon (Profiles Pg 4 and 5). (Plate 1-1).

HUMIC PODZOLS

Definition: Humic Podzols are Podzols having a B horizon in which a subhorizon contains dispersed organic matter and aluminium and lacks sufficient free iron to turn redder on ignition.

Free iron has not been fully defined, but in the definition of Humod (USDA 1973), which is equivalent to the Humic Podzol, the ratio of free iron (by citrate-dithionite extraction) to carbon has to be less than 0.2. Very few measurements of free iron content have been made on Sabah soils, but from the available figures and from the observed changes in colour of the soils after ignition, it seems that soils with less than 0.2% total iron will fail to turn redder on ignition. Such low levels of total iron are relatively rare so that Humic Podzols are of limited occurrence.

Karamatoi Family

The Karamatoi Family (Figure 1-11) is the only family of Humic Podzols which has been described in Sabah. The soils of this family are formed on coarse-textured alluvium on terraces and old beaches. They are all well to excessively drained and have coarse textures in all horizons. Profiles typically have O, A, E, Bh and C horizon sequences. The colours of the E horizon range from brown to light grey or white and the spodic horizons which are usually about 10 cm (4 in) thick are reddish black to dark greyish brown. The horizons below the spodic horizon vary from dark brown or yellowish brown to very pale brown. Profiles with indurated and compact E horizons and those lacking induration and compaction are equally common. The described profiles lack pebbles and concretions.

Cation enchange capacities are at a maximum at the surface, at a minimum in the E and show a subsidiary peak in the spodic horizons. The actual values in the spodic horizons are mostly below 10 meq% and in the E horizon are often 1 meq% or less. The lowest pH values of about 4 are usually found in the surface horizons. Exchangeable cations are negligible except in the O horizons. Total iron levels are below 0.2% in nearly all horizons, but both iron and aluminium show an appreciable accumulation in the spodic horizon. Total titanium figures available for one profile show no variation between E and B horizons, but because titanium occurs mostly in resistant minerals it is little affected by podzolization. Quartz is the dominant mineral of the clay size fraction of the spodic horizon, but it decreases in the lower horizons, while vermiculite and kaolinite increase from minor amounts to dominance (Profile Ph 1) (Plate 1-16).

ORTHIC PODZOLS

Podzols lacking the diagnostic features of Placic Gleyic or Humic Podzols are termed Orthic Podzols. The spodic horizons of Orthic Podzols contain appreciably more iron than do the same horizons of Humic Podzols. However, because of the lack of information on the soil colour after ignition and free or total iron contents, it is possible that some profiles classified as Orthic may in fact be Humic Podzols. Orthic Podzols normally have O, A, E, Bh, Bfe, B and C horizon sequences.

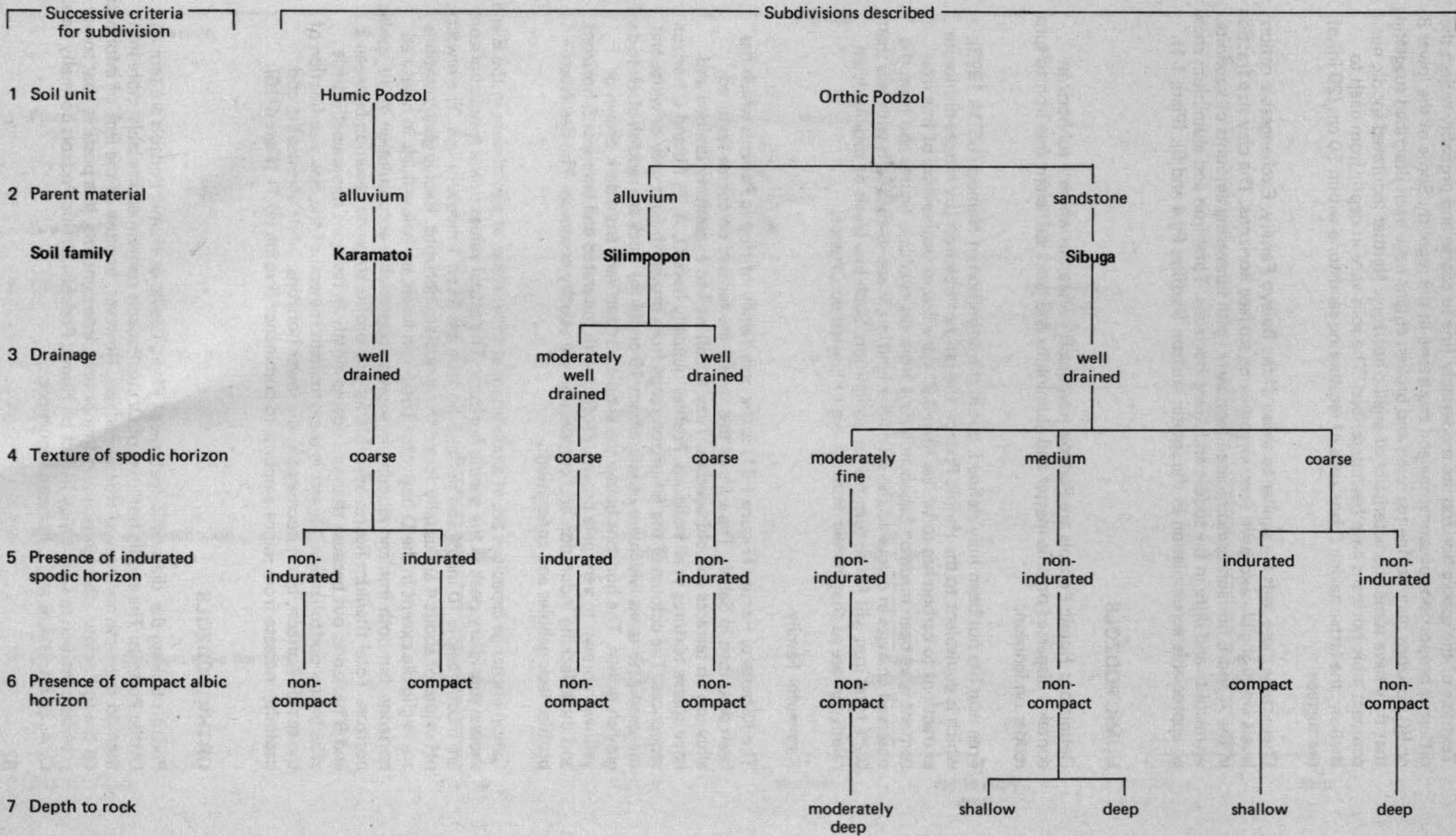


FIGURE 1-11 Humic and Orthic Podzols: criteria for subdivision and subdivisions described

Two families have been described; the Silimpopon Family occurs on alluvium on old beaches and terraces and the Sibuga Family occurs on sandstone hills and mountains.

Silimpopon Family

The Silimpopon Family (Figure 1-11) comprises Orthic Podzols on medium- to coarse-textured, sometimes pebbly, alluvium occurring on terraces. The soils are moderately well drained to excessively drained, but the slight drainage imperfections of the former are only apparent in the lowest horizons. The described profiles all have coarse-textured spodic horizons, but it is possible that finer textured profiles do occur. Some of the lower B horizons show increases in clay which may be the result of sequential deposition. None of the described profiles have compact albic horizons but indurated spodic horizons do occur.

The soils are strongly to extremely acid. Cation exchange capacities are at a maximum in surface organic rich horizons and at a minimum in the E horizons; in the spodic horizons values range between 10 and 20 meq%. Exchangeable cations are negligible in all horizons. Total iron and alluminium have maximum values in the spodic horizon. (Profile Po 1) (Plate 1-2).

Sibuga Family

The soils of the Sibuga Family which occur on sandstone hills and mountains are all well or excessively drained. Textures of the albic E horizons are normally coarse and in the spodic horizons they range from moderately fine to coarse. Below the spodic horizon there is sometimes a clear increase in clay content. Indurated spodic and compact albic horizons are rare. The soils range from deep to shallow, the latter having C horizons of weathering sandstone within 50 cm (20 in) of the surface.

The pH of these soils ranges between 4 and 5. Cation exchange capacities, in general, are low, with values below 15 meq% except in some surface horizons rich in organic matter and some horizons with higher clay contents. Exchangeable cation levels are low to negligible in all but the surface horizons. There is usually an accumulation of iron and aluminium in the spodic horizons. The accumulation of iron in the B2 fe horizon of 1 profile was sufficient for goethite to be detectable by X-ray analysis and in the only profile for which data is available, quartz is dominant in the E and upper horizons, with kaolinite becoming dominant in the lower horizons; in the C horizon of weathering sandstone illite is dominant, with minor amounts of kaolinite and no more than traces of quartz. The implication is that illite and kaolinite are being weathered or destroyed in the upper parts of the profile to leave quartz dominant (Profile Po 2).

Ferralsols

GENERAL DESCRIPTION

Definition: Ferralsols are soils which have an oxic B horizon.

In general Ferralsols are deep, well drained soils with shallow ochric A and deep oxic B horizons. The main physical features of oxic horizons are relatively uniform colours and textures and fine subangular blocky or crumb structures. They are strongly weathered with low to very low cation exchange capacities (< 16 meq/100g clay), very low amounts of exchangeable calcium, magnesium and potassium and strongly acid reaction. The dominant minerals of the clay size fraction are kaolinite, goethite or both.

Rhodic, Xanthic and Orthic Ferralsols have been described in Sabah. They have been separated into soil families and lower categories (Table 1-7 and Figure 1-12) using as criteria parent material, colour and texture of the oxic horizons and drainage.

RHODIC FERRALSOLS

Definition: Rhodic Ferralsols have red to dusky red B horizons (rubbed soil has hues redder than 5YR with a moist value of less than 4 and a dry value not more than one unit higher than the moist value). Two families have been described, namely the Apas Family on intermediate igneous rocks and the Pinianakan Family on colluvium derived from ultrabasic igneous rocks.

TABLE 1-7 Ferralsols: soil families and the associations in which they commonly occur

Soil unit	Parent material	Family	Association
Rhodic Ferralsol	Intermediate igneous rocks	Apas	Apas Kennedy Bay
	Ultrabasic igneous rocks	Pinianakan	Bidu Bidu
Xanthic Ferralsol	Alluvium	Tungau	Karamuak
	Basis igneous rocks	Jarangan	Table
Orthic Ferralsol	Alluvium derived from ultrabasic igneous rocks	Nobusu	Binalik
	Ultrabasic igneous rocks	Ambun	Bidu Bidu Malubok
	Basic igneous rocks	Table	Table
	Alluvium	Benuou	Brantian Dalit

Apas Family

Soils of the Apas Family occur on the slopes of low hills formed of volcanic ash. They are deep, fine-textured soils, with clay contents ranging from 60-80%. They are well or moderately well drained. Of the 2 profiles described the colour of the well drained profile is red to reddish brown and the moderately well drained profile is red, with light yellowish brown mottles and many small iron concretions in the lower parts of the oxic horizon. Cation exchange capacities are in the 10-15 meq/100g clay range. Kaolinite is the dominant clay mineral.

Pinianakan Family

The soils of this family are very similar to the Orthic Ferralsols of the Ambun Family (see below) and differ only in having reddish brown colours in the oxic horizon. They are formed on steep slopes of colluvium derived from ultrabasic igneous rocks. (Plate 1-15).

XANTHIC FERRALSOLS

Definition: Xanthic Ferralsols have yellow to pale yellow B horizons (rubbed soil has hues of 7.5YR or yellower with a moist value of 4 or more and a moist chroma of 5 or more.)

Two families are defined, namely the Tungau Family on alluvium and the Jarangan Family on basalt.

Tungau Family

Soils of the Tungau Family have been described on dissected terraces. They are deep and well drained, with strong brown fine-textured oxic horizons containing between 45 and 75% clay; gravel and stones may occur in the lower horizons (Profile FX 1) (Plate 1-14).

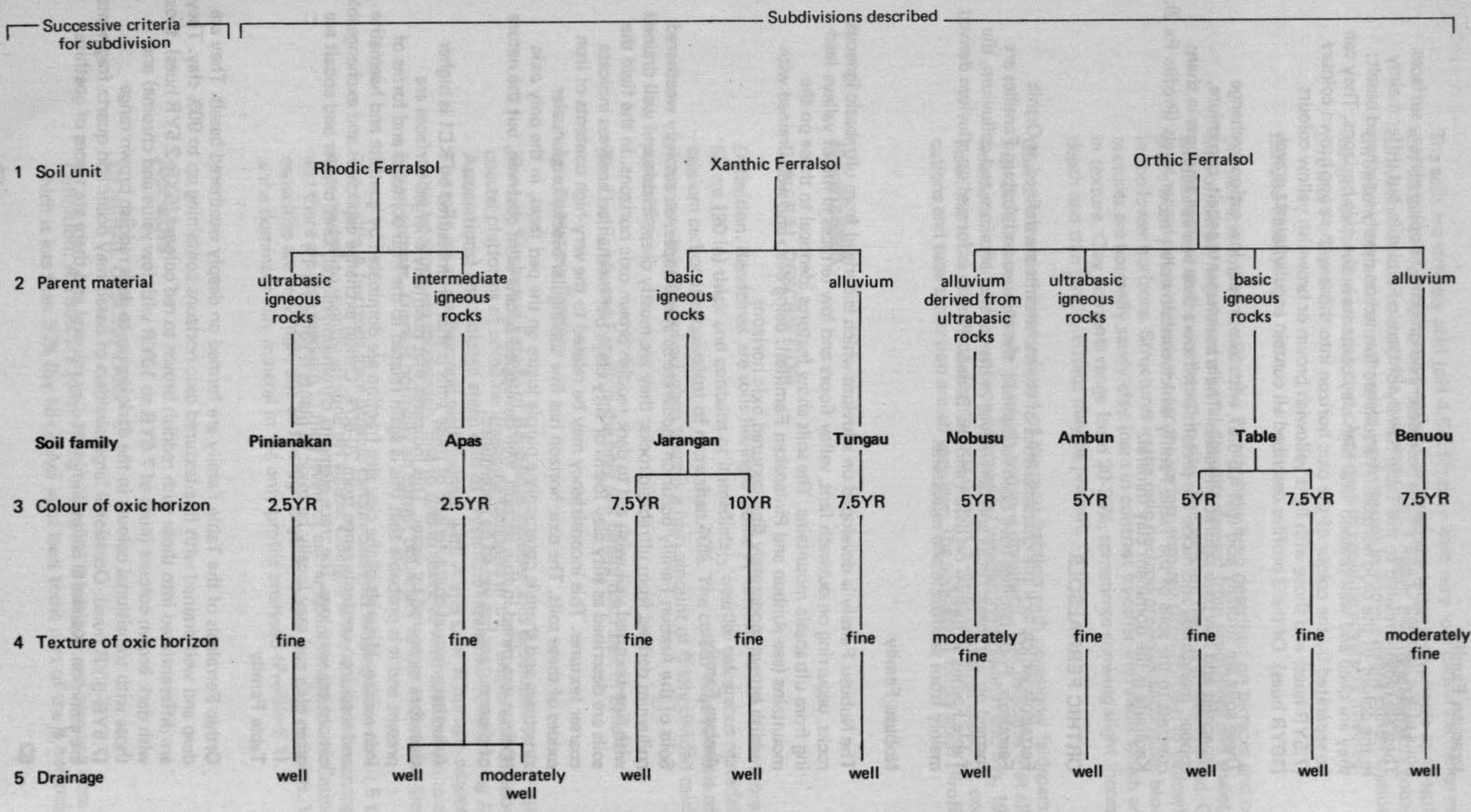


FIGURE 1-12 Ferralsols: criteria for subdivision and subdivisions described

Jarangan Family

Soils of the Jarangan Family have been described on gently sloping plateau surfaces. They are closely related to the Table Family of Orthic Ferralsols, but differ mainly in the colour of the oxic horizon. The soils are formed on deeply weathered basalt; they are deep and well drained with high clay contents in the oxic horizons. They can be separated by the colour of the oxic horizon into those with strong brown colours (7.5YR hues) and those with light yellowish brown or brownish yellow colours (10YR hues). Of the 3 profiles described all contain angular quartz gravel.

These soils are strongly acid (pH 4.5-5.5), with low or very low cation exchange capacities and low base saturation values. The trace elements cobalt, chromium, copper, manganese and nickel are present in no more than average amounts in sharp contrast to the soils of the Table Family which contain much higher levels (Profile Fx 2). Kaolinite is the dominant clay mineral.

ORTHIC FERRALSOLS

Ferralsols which lack the characteristics of the other units are defined as Orthic Ferralsols. Four families have been recognised; the Nobusu and Ambun Families are formed on ultrabasic rocks and derivatives in the form of alluvium and colluvium, the Table Family is formed on basalt and the Benuou Family is formed on alluvium derived mainly from sandstone and mudstone.

Nobusu Family

The Nobusu Family is developed on alluvium which is derived from ultrabasic igneous rocks, occurring on outwash fans, valley floors and low terraces in minor valleys leading from ultrabasic mountains. The soils show features identical to those on the mountains (see Ambun and Pinianakan Families), being deep and well drained with reddish brown moderately fine-textured oxic horizons

Ambun Family

Soils of the Ambun Family occur on moderate to steep slopes, on strongly weathered colluvium derived from ultrabasic rocks; they are mostly deep, friable and well drained with fine-textured yellowish red to dark reddish brown oxic horizons. In the field the soils are described as silty clay loams or silty clays but mechanical analyses indicate coarser textures. This inconsistency may be related to the very high contents of iron oxides of these soils. The oxic horizon has fine subangular blocky or granualar structures and there is commonly a purple lustre on the ped faces, in the only oxic horizon examined in thin section, well developed cutans were observed, but the nature of these cutans has yet to be determined.

A further unusual characteristic of these soils is that pH measured by KC1 is higher than that measured by water. This indicates that positively charged surfaces are present and it is probable that this is again related to the high contents and forms of iron oxides. Minerals of the clay size fraction are dominated by goethite and haematite and total iron contents range from 20-60%. Cation exchange capacities and exchangeable cations are very low. The trace elements chromium, nickel, zinc, copper and cobalt are often high and may locally be toxic to plants (Profile Fo 1).

Table Family

Orthic Ferralsols of the Table Family are formed on deeply weathered basalt. They are deep and well drained with fine-textured oxic horizons containing up to 90% clay. They are differentiated into those with reddish brown to red colours (5YR-2.5YR hues), those with dark brown colours (hues of 7.5YR to 10YR with low value and chroma) and those with transitional colours in the dark brown to dark reddish brown range (7.5YR-5YR hues). Occasional large boulders of basalt may occur and quartz fragments are common. Kaolinite is the dominant clay mineral and there are traces of goethite.

The soils are strongly acid (pH 4.5-5.5); they have very low cation exchange capacities and contents of exchangeable cations although the latter are variable as a result of cultivation. In the only profile analysed (Allen, 1966) the trace elements cobalt, chromium, copper and manganese were present in above average concentrations; the manganese levels were such that plant growth could be adversely affected. (Profiles Fo 2 and 3).

Benuou Family

Orthic Ferralsols of the Benuou Family have been described on terraces and on low hills on deeply weathered alluvial deposits derived from sandstones and shales, or on sandstones and shales weathered in situ. The soils are deep and well drained. Colours grade from yellowish brown near the surface through strong brown to yellowish red in the lower horizons. Structures in the oxic horizon are weak subangular blocky and textures are normally sandy clay loam in contrast to other Ferralsols which are finer in texture. Clay contents range from 20-35%, sometimes showing slight increases with depth and thin patchy cutans may be present.

Quartz is the dominant mineral of the sand fraction with occasional feldspars and less than 0.5% heavy minerals, of which zircon is dominant. This indicates that all weatherable minerals have been removed by weathering (Eswaran and Sys, 1971). Kaolinite is the dominant clay mineral present. Cation exchange capacity, exchangeable cations and base saturation are all very low. The soils are strongly acid. (Profile Fo 4).

Rendzinas

GENERAL DESCRIPTION

Definition: Rendzinas are soils having a mollic A horizon, which is not more than 50 cm (20 in) thick and contains or immediately overlies calcareous material, with a calcium carbonate equivalent of more than 40%. The colour requirements of the mollic A horizon may be waived when there is a high amount of finely divided calcium carbonate.

The Loc Sambuang Family is the only soil family described in Sabah.

Loc Sambuang Family

The Loc Sambuang Family of Rendzinas includes soils developed on low hills and coastal platforms of coralline linestome (mapped in the Tungku and Semporna Associations) and isolated steep hills of crystalline limestone (Gomantong Association). The soils are all shallow and well drained, with A and C or R horizon sequences. The mollic horizons are moderately fine to fine in texture, with dark brown to dark reddish brown colours. There is normally an abrupt boundary to the underlying limestone.

The mollic A horizons have organic carbon contents ranging from about 5 to 11% and near neutral to slightly alkaline pH values. Calcium is the dominant exchangeable cation and there are also medium to high levels of exchangeable magnesium. Cation exchange capacities are very high, due to the high organic matter and clay contents. Vermiculite is the dominant clay mineral in the only profile analysed (Profile E 1).

Acrisols

GENERAL DESCRIPTION

Definition: Acrisols are soils having an argillic B horizon and having a base saturation, which is less than 50% (by NH_4OAc) in at least some part of the B horizon.

An argillic horizon is one that contains illuvial layer-lattice clays and usually has cutans which amount to more than 1% in some part of the horizon. It should contain more total clay than does an eluvial horizon above it (see Appendix 2). The evidence for cutans is sometimes not clear, as they are not always identifiable in the field and their study in the laboratory is somewhat subjective. Further, because the necessary difference in clay contents between an E and a Bt horizon can be as low as 3% (i.e. within the limits of experimental error in mechanical analysis) the reported differences are not always reliable. However, even with these doubts over the definition of argillic horizons, Acrisols are probably the most widespread soils in Sabah; they occur on a wide range of parent materials and sites.

Gleyic, Humic, Ferric, and Orthic Acrisols have been described in Sabah. Each of these units has been separated into families on the basis of parent materials (Table 1-8) and the families have been further divided using the following criteria:

1. Profile drainage
2. Texture of the upper argillic horizon
3. Colour of argillic horizon:
   i. Hues of 5YR with chromas of 4 or less or redder hues.
   ii. Hues of 5YR or 7.5YR with chromas of more than 4
   iii. Hues of 7.5YR with chromas of 4 or less or yellower hues
   iv. Presence or absence of many mottles (5YR or redder with chromas of 6 or more) (Ferric Acrisols only)
4. Depth
5. Stoniness

TABLE 1-8 Acrisols: soil families and the associations in which they commonly occur

Soil unit	Parent material	Family	Association
Gleyic Acrisol	Alluvium	Inanam	Kinabatangan Sapi Binalik Labau
	Tuffaceous rocks	Koung	Lungmanis Rumidi Kalabakan Kennedy Bay
	Sandstone and mudstone	Gunong Alab	Maliau Trusmadi
	Mudstone	Masaum	Lungmanis Silabukan Rumidi Kalabakan
Humic Acrisol	Sandstone and mudstone	Kiau	Trusmadi
Ferric Acrisol	Alluvium	Lumisir	Karamuak Labau Brantian
	Basic igneous rocks	Beruang	Beruang

TABLE 1-8 (continued)

Soil unit	Parent material	Family	Association
Ferric Acrisol (continued)	Sandstone and mudstone	Sipit	Rumidi Sipit Kretam Dalit Tengah Nipah Kennedy Bay
	Mudstone	Batang	Lungmanis Silabukan Rumidi Kalabakan
Orthic Acrisol	Alluvium derived from basic and ultrabasic rocks	Katai	Binalik Tapang Karamuak
	Alluvium	Paliu	Brantian Sook Sinarun Binkor Labau Karamuak
	Basic and intermediate igneous rocks	Kinabutan	Tapang Orchid Plateau Apas Mentapok Kennedy Bay
	Tuffaceous rocks	Dagat	Sipit Dagat Gumpal Bang
	Chert	Mensuli	Gumpal Bang
	Mudstone	Kumansi	Lungmanis Silabukan Rumidi Kalabakan Kretam Mawing Dagat Crocker Trusmadi
	Sandstone and mudstone	Tanjong Lipat	Rumidi Kalabakan Kretam Dalit Mawing Gumpal Lokan Bang Maliau Crocker Trusmadi
	Sandstone	Kapilit	Maliau Serudong Crocker Lokan Dalit Kretam Gumpal

GLEYIC ACRISOLS

Definition: Gleyic Acrisols are Acrisols having a gleyic horizon.

Four families have been defined, namely the Inanam, Koung, Gunong Alab and Masaum Families.

Inanam Family

The soils of the Inanam Family (Figure 1-13) are formed on fine- to coarse-textured, rarely stony, alluvium occurring on floodplains, valley floors and terraces. They are imperfectly to poorly drained due to groundwater fluctuations. The imperfectly drained soils have gleyic horizons below 50 cm (20 in) and have A, E, Bt, Btg or Cg horizon sequences; poorly drained soils have gleyic horizons within 50 cm (20 in) of the surface and have A, E or Eg, Btg and Cg horizon sequences; shallow O horizons, composed largely of raw humus, may also occur. The E horizons are often strongly leached and pale coloured. The argillic horizons, which occur above gleyic horizons commonly have matrix colours of 7.5YR hue, with chromas of less than 4, or yellower hues; they generally have fine or moderately fine textures. Cutans occur in the argillic horizons of most profiles but their degree of development is variable; micromorphological studies were made on thin section samples of 3 profiles and these all showed clear clay cutans. Soils containing pebbles and gravel are comparatively rare.

Most of the surface horizons of these soils have higher cation exchange capacities and exchangeable cation values than the subsurface horizons. The cation exchange capacities of the upper argillic horizons are low, with values generally below 15 meq%. The percentage base saturation figures are mostly below 20% and there are generally low levels of exchangeable cations. Soil pH values range from 4.0-5.5 and generally increase with depth. Profiles with base saturation values between 35 and 50%, generally as a result of above average levels of exchangeable magnesium and sometimes of calcium, are clearly intergrades to Gleyic Luvisols of the Buran Family.

Clay minerals were examined in 2 profiles; in one, quartz was dominant with lesser amounts of poorly crystallised kaolinite and anatase together with vermiculite in the upper argillic horizon; in the other, vermiculite was dominant in all horizons with moderate amounts of kaolinite in the upper horizons decreasing to trace amounts in the lower horizons; illite was present in trace amounts throughout. (Profiles Ag 1, 2 and 3) (Plate 1-10).

Koung Family

The Koung Family is comprised of Gleyic Acrisols formed on tuffaceous rocks. The only reported profile (Thomas 1967a) is described on bentonitic shale. It is imperfectly drained with clay contents exceeding 65% in the argillic horizon. Cation exchange capacities are mostly high, and probably reflect the clay mineralogy of the profile; montmorillonite is dominant with smaller amounts of illite and traces of kaolinite in all horizons. Exchangeable magnesium levels are high or very high and exchangeable potassium levels are above average in all horizons (Profile Ag 4).

Gunong Alab Family

Gleyic Acrisols of the Gumong Alab Family (Figure 1;14) are formed on sandstone and mudstone on the gentle slopes of low hills and on a range of slopes at high altitudes. They are imperfectly to poorly drained, due to a combination of the effects of surface and groundwater at low altitudes and mainly to surface water effects, under moist conditions, at high altitudes. Profiles with drainage imperfections caused by surface water have shallow A horizons, Eg or Btg horizons and well drained lower horizons. Profiles with groundwater gleying have argillic horizons which become gleyic with depth; those with gleyic horizons below 50 cm (20 in) are classed as imperfectly drained and those with gleyic horizons above 50 cm are poorly drained. The argillic

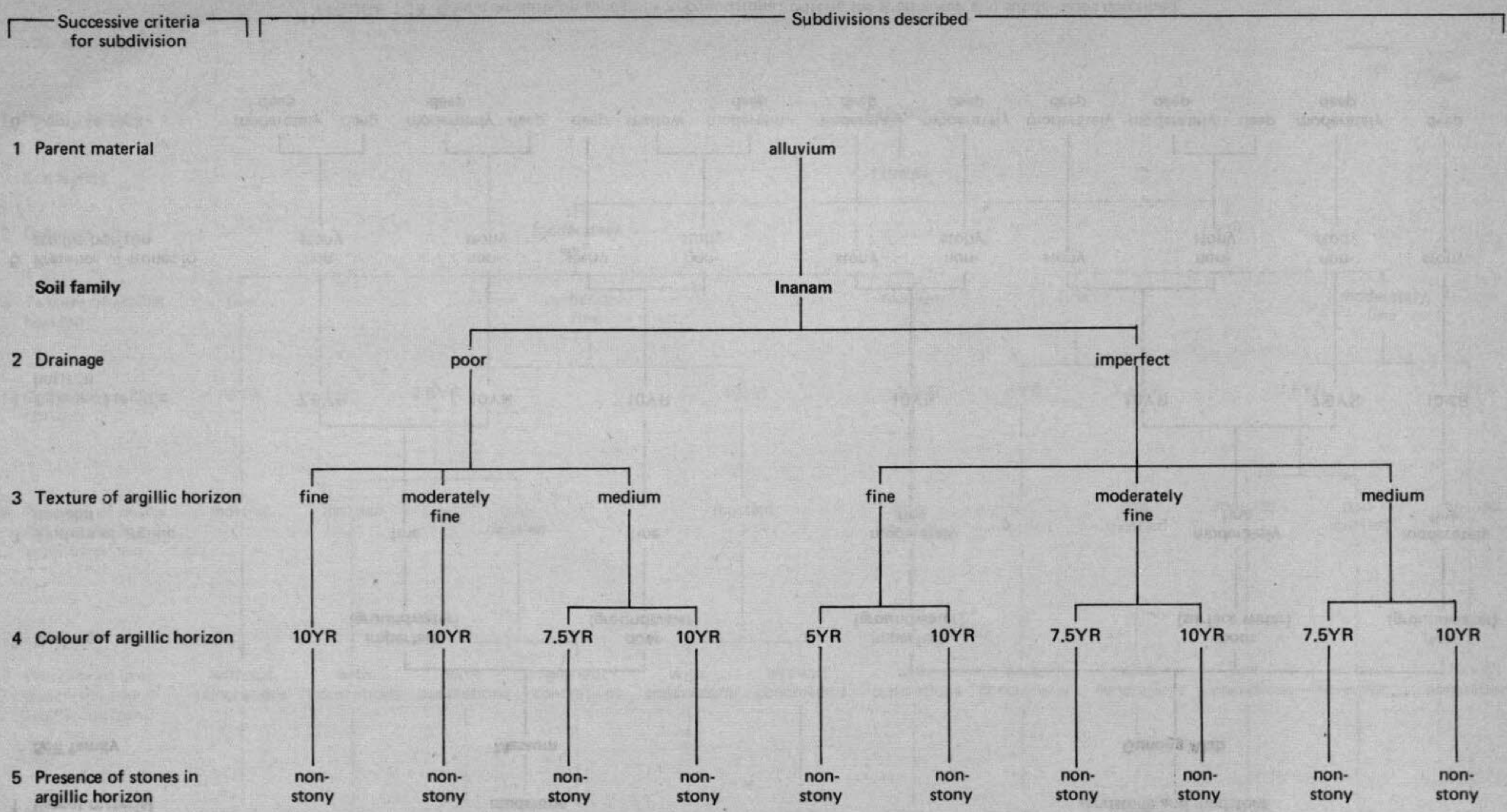


FIGURE 1-13 Gleyic Acrisols on alluvium: criteria for subdivision and subdivisions described

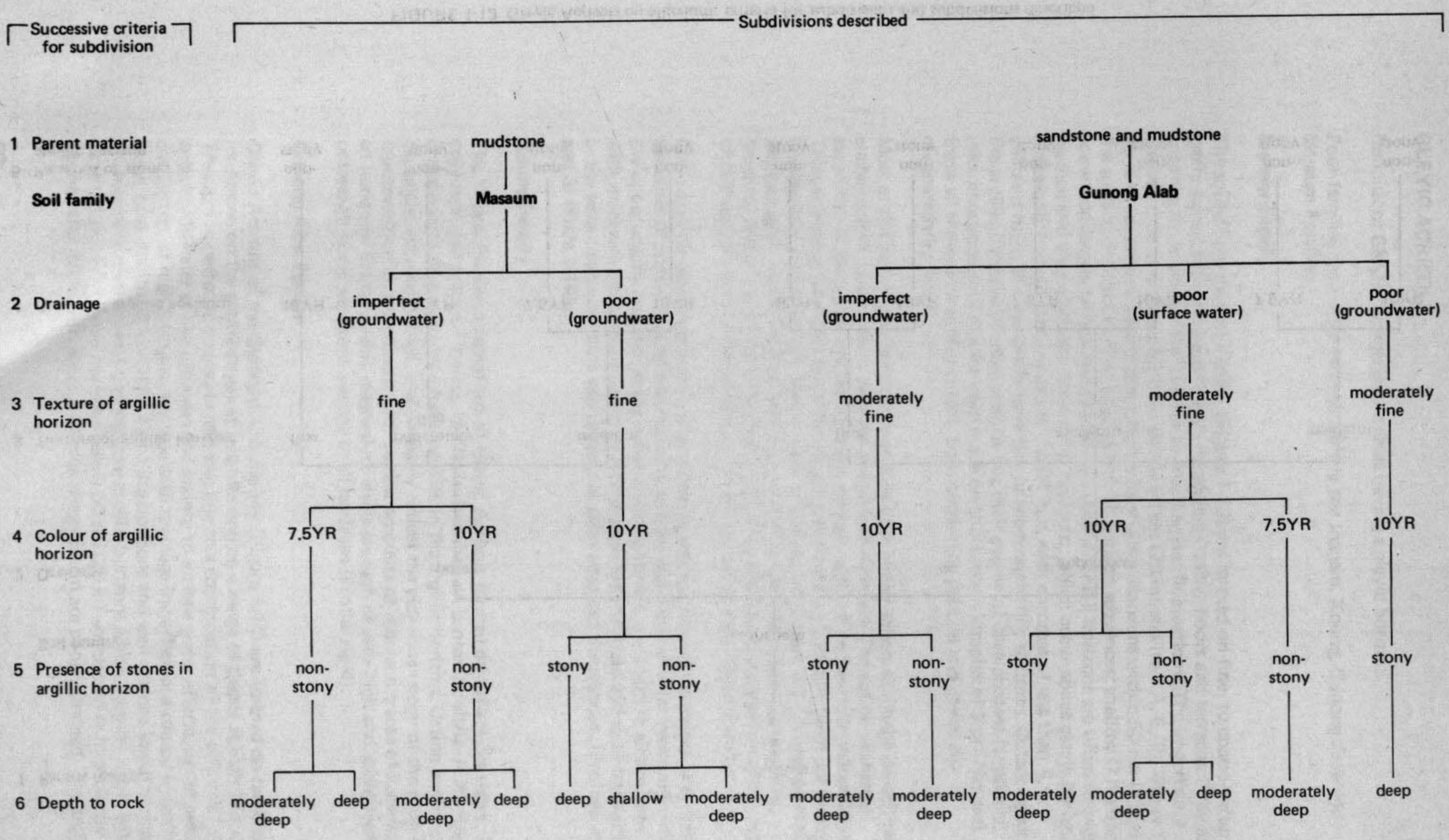


FIGURE 1-14 Gleyic Acrisols on sandstone and mudstone: criteria for subdivision and subdivisions described

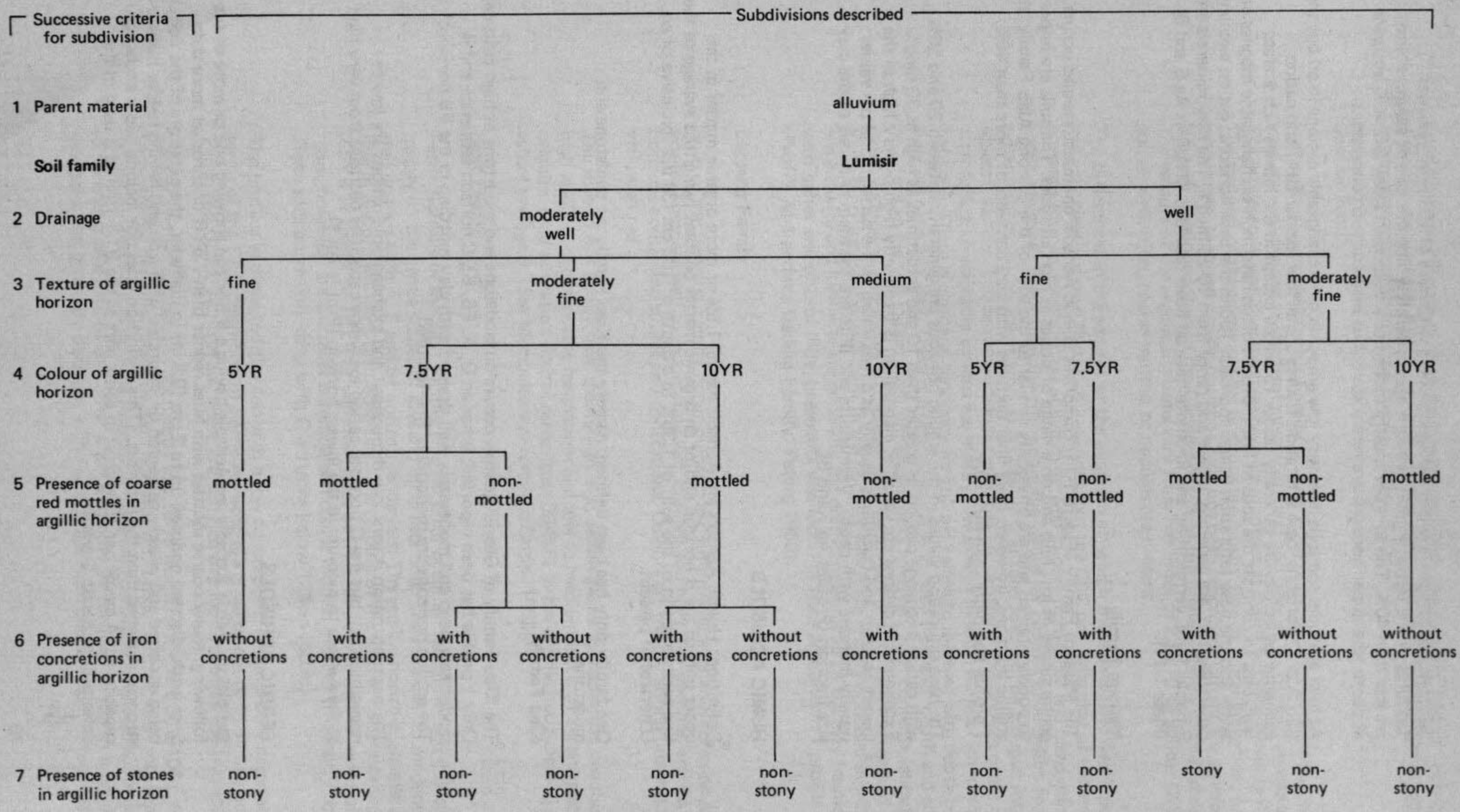


FIGURE 1-15 Ferric Acrisols on alluvium: criteria for subdivision and subdivisions described

horizons not affected by gleying have colours with hues of 10YR or yellower. Textures of the upper argillic horizons are moderately fine or coarser; clay contents are less than 40%. The soils are mostly moderately deep with stony BC or C horizons at depth; the upper horizons are rarely stony but may contain concretions.

At high altitudes the soils have very low amounts of exchangeable cations in all but the thin A or O horizons; base saturation figures are all low (below 10%) and cation exchange capacities are generally below 15 meq% except in the humus-rich surface horizons. In contrast the soils at low altitudes often have high exchangeable magnesium levels and the base saturation values approach 100 in the base horizons; cation exchange capacities, too, are generally higher and range from 10-25 meq%. The clay minerals are variable; illite, vermiculite, and kaolinite have all been recorded. (Profiles Ag 5 and 6) (Plate 1-11).

Masaum Family

The Masaum Family (Figure 1-14) comprises Gleyic Acrisols on mudstone and occurs on gentle slopes of low hills and on a range of slopes at high altitudes. The soils are imperfectly to poorly drained and are physically similar to the soils of the Gunong Alab Family; the argillic horizons, however, have finer textures with clay contents of more than 40%; 1 profile had more than 60% clay.

The base saturation values in the argillic horizons are generally between 20 and 50% with cation exchange capacities greater than 10 and sometimes as high as 30 meq%. Exchangeable cations are variable; magnesium is frequently high or very high in the lowest horizon and calcium is usually at a maximum at the surface. Soil pH values usually increase with depth. Vermiculite and illite are the main minerals of the clay size fraction (Profiles Ag 7 and 8).

HUMIC ACRISOLS

Definition: Humic Acrisols are Acrisols having 1.5% or more organic matter in the upper part of the B horizon and/or an organic matter content (weighted average of the fine earth fraction of the soil) of 1.35% to a depth of 100 cm (39 in), exclusive of an O horizon if present.

One family only has been defined, namely the Kiau Family on sandstone and mudstone.

Kiau Family

The Kiau Family of Gleyic Acrisols occurs on sandstone and mudstone at high altitudes. Only 1 profile has been reported; it has an O, A, EB, Bt, C horizon sequence and is moderately deep and moderately well drained with gley mottling in the EB horizon; The argillic horizons are moderately fine-textured.

The base saturation is very low throughout and exchangeable cations are low to negligible in all but the O horizon; cation exchange capacities decrease from very high at the surface to medium in the lowest horizon (Profile Ah 1).

FERRIC ACRISOLS

Definition: Ferric Acrisols are Acrisols having a B horizon showing one or more of the following: many coarse mottles with hues redder than 7.5YR or chromas more than 5, or both; discrete nodules, up to 2 cm (0.8 in) in diameter, the exteriors of the nodules being enriched and weakly cemented or indurated with iron and having redder hues or stronger chromes than the interiors. (This definition does not include a low exchange capacity (<24 meq% per 100g clay) in some part of the B horizon as is used in the definition of Ferric Luvisols).

Four families of Ferric Acrisols have been described; they are the Lumisir Family on alluvium, the Beruang Family on basic igneous rocks, the Sipit Family on sandstone and mudstone and the Batang Family on mudstone.

Lumisir Family

Ferric Acrisols of the Lumisir Family (Figure 1-15) occur on alluvial terraces. The soils are well drained or moderately well drained and have A, E, Bt horizon sequences. The moderately well drained soils have gley mottles at depth but lack gleyic horizons. The textures of the upper argillic horizons are mostly fine or moderately fine; soils with coarse-textured argillic horizons have not been described. Cutans are generally less well developed than in the Gleyic Acrisols of the Inanam Family described above. The colours of the argillic horizons vary from red (hues of 2.5YR) to yellow (2.5Y) and by definition, coarse mottles or nodules are present.

The differences in the sources of the alluvium on which these soils have developed are not very clearly shown by the soil analyses, but the CEC per 100g clay of the argillic horizons of soils developed on alluvium derived in part from basic and ultrabasic rocks, are much lower than the corresponding values for profiles on alluvium from other sources. With further work it is possible that such soils will be grouped into a separate family. The cation exchange capacities are generally low and are often below 10 meq%. Exchangeable cations are mostly low except in some humus-rich surface horizons. There is a general tendency for soil pH values to increase with depth but they are generally low. There is a general increase in total iron with depth and soils on alluvium derived in part from ultrabasic rocks have very high contents (about 20%); total aluminium also shows an increase with depth but this is much less marked and there is no apparent enrichment in the nodules which are greatly enriched in iron. Vermiculite and kaolinite are generally the dominant minerals of the clay fraction with minor amounts of illite; haematite was found in trace amounts in 1 profile only. (Profile Af 1 and see Gading Family: Paton, 1963).

Beruang Family

Soils of the Beruang Family occur on basic and intermediate igneous rocks on moderate slopes. They are well to moderately well drained and have fine-textured argillic horizons containing stones and concretions. Colours are mainly strong brown to yellowish red.

The soils of this family have medium to high cation exchange capacities, medium to high levels of exchangeable magnesium and low to medium levels of exchangeable calcium; base saturation figures range from 30-50% in the argillic horizons; soil pH values average 5. (See Membalua sub-family in Paton, 1963).

Sipit Family

Ferric Acrisols of the Sipit Family (Figure 1-16) occur on sandstone and mudstone mainly on the gentle slopes of low and moderate hills. They are well to moderately well drained with A, E and Bt horizon sequences. The argillic horizons are moderately fine in texture with less than 40% clay. The colours of the argillic horizons range from 2.5YR or redder to 10YR or yellower; hues of 5YR, or 7.5YR with chromas of 4 or more, however, are the most common and coarse reddish mottles frequently occur. These soils are mainly deep with C horizons below 125cm (50 in).

The profiles without mottles and with a few concretions, incompletely described in terms of the FAO definition of Ferric Acrisols, are close to the dividing line between Ferric and Orthic Acrisols and there is clearly an overlap between these two soil units.

Cation exchange capacities are mostly low (5-15 meq%) and the CEC's/100g clay of some argillic horizons meet the requirements of the oxic horizon; such soils are transitional to Ferralsols. Base saturation values are generally below 20%. Amounts of exchangeable cations and other plant nutrients are medium to low in most surface horizons and generally decrease in the subsurface horizons; medium to high levels of

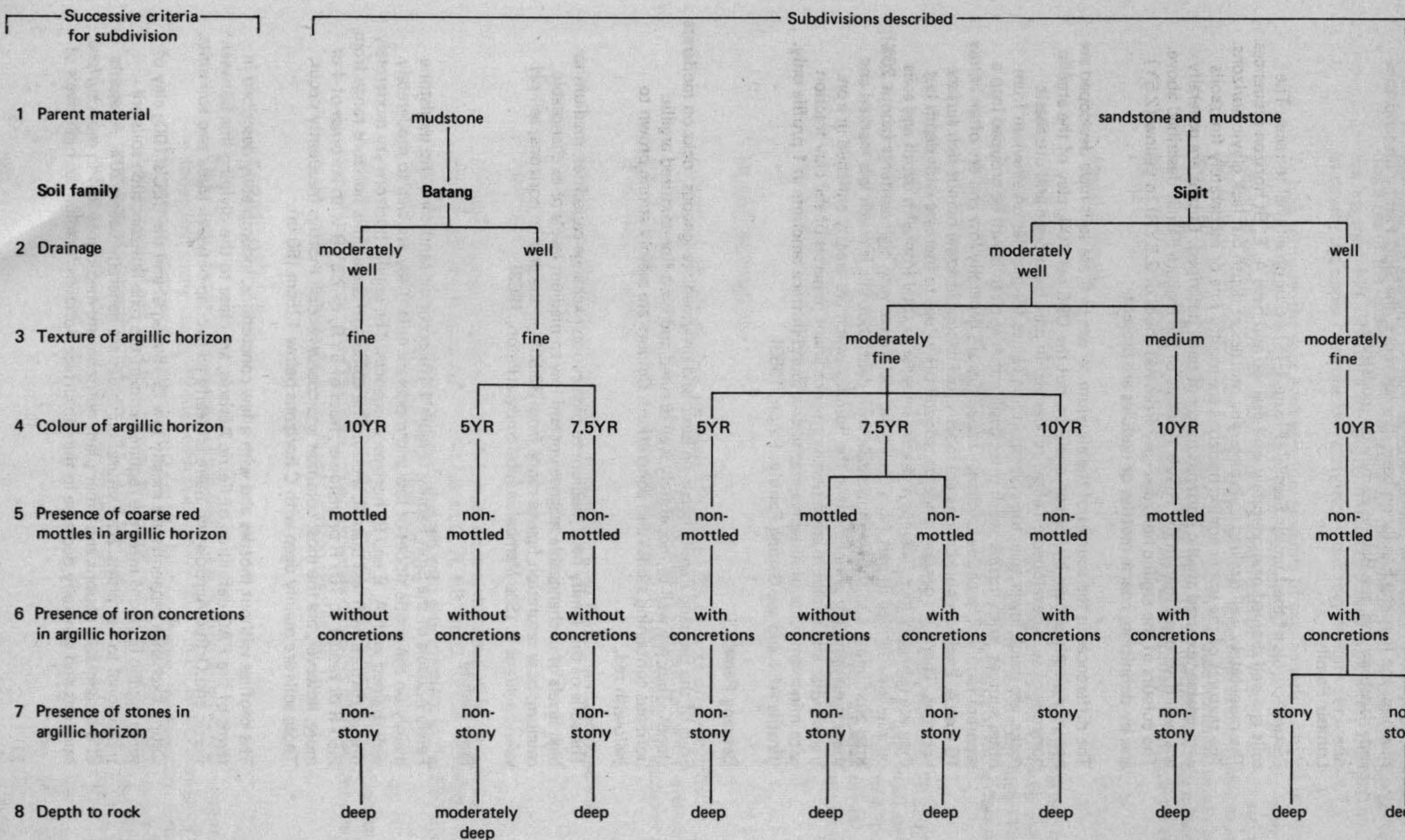


FIGURE 1-16 Ferric Acrisols on sandstone and mudstone: criteria for subdivision and subdivisions described

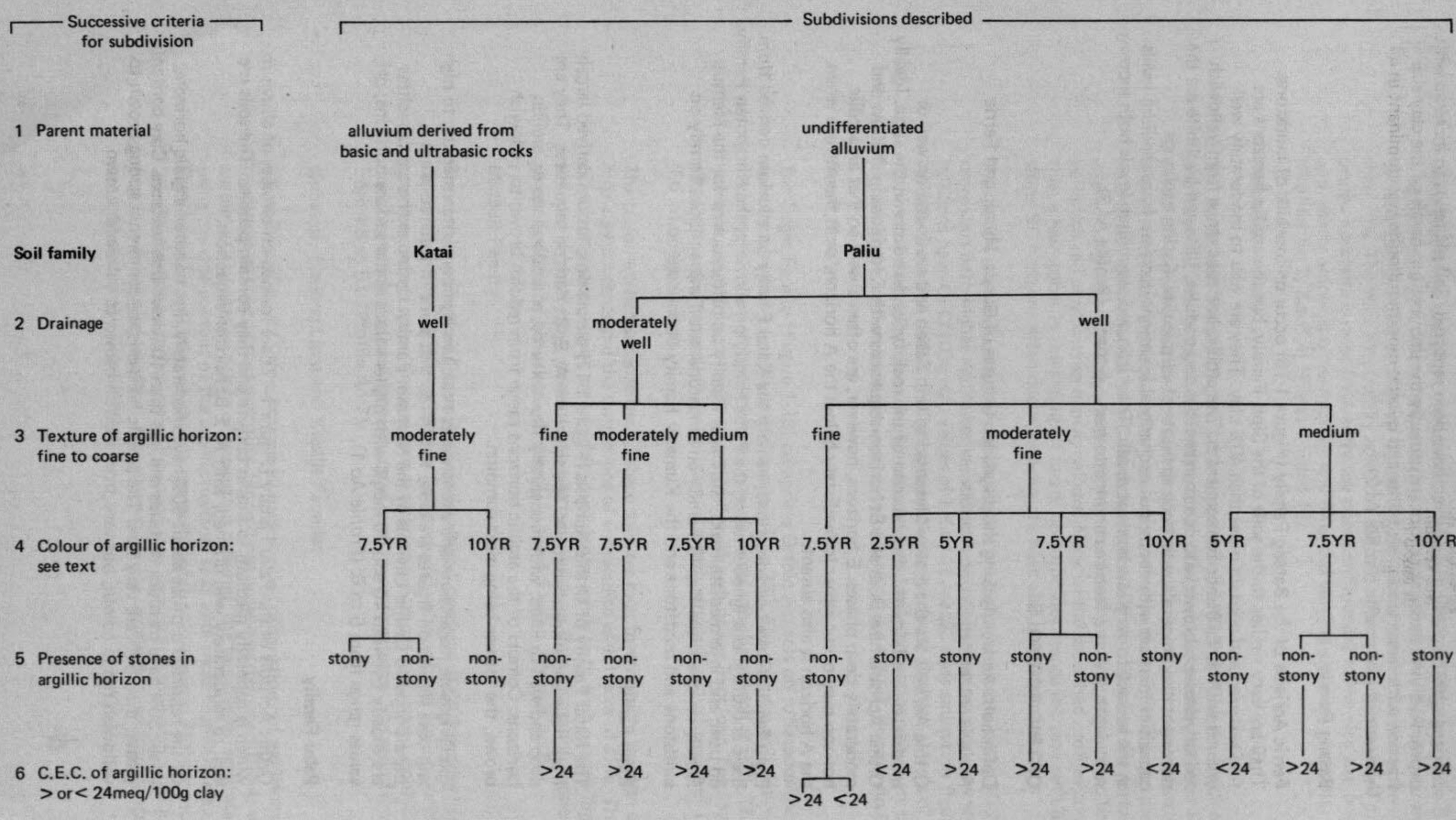


FIGURE 1-17 Orthic Acrisols on alluvium: criteria for subdivision and subdivisions described

exchangeable magnesium, however, have been reported. Soil pH tends to increase with depth. Kaolinite and vermiculite are usuaully the dominant minerals of the clay size fraction with lesser amounts of illite and quartz; montmorillonite was dominant in all horizons of one profile (Profile Af 2).

Batang Family

Ferric Acrisols of the Batang Family (Figure 1-16) occur on low hills of mudstone. They are very similar to the soils of the Sipit Family, but the argillic horizons are fine-textured and contain more than 40% clay. They are well to moderately well drained with A, E, Bt horizon sequences. The argillic horizons range from yellowish red to yellowish brown with common mottles and nodules. Illite and kaolinite are the dominant clay minerals with trace amounts of vermiculite. Cation exchange capacities increase with depth, but exchangeable cations decrease from medium levels in the surface to very low levels at depth. Total iron and aluminium levels both increase with depth; this is a feature common to many Acrisols. (Profile Af 3).

ORTHIC ACRISOLS

Definition: Acrisols lacking the diagnostic features of Gleyic, Humic and Ferric Acrisols are termed Orthic Acrisols.

Orthic Acrisols are the most widespread soils in Sabah and are found on well or moderately well drained sites on most of the rock types that occur in the state. Ideally Orthic Acrisols have A, E and Bt horizon sequences with C horizons in shallow and moderately deep phases. E horizons, however, are often absent so that an argillic horizon may occur either immediately below the A horizon, or at the surface when the A horizon is also absent.

Eight families have been described, namely the Katai Family on alluvium derived from basic and ultrabasic igneous rocks, the Paliu Family on alluvium, the Kinabutan Family on basic and intermediate rocks, the Dagat Family on tuffaceous rocks, the Mensuli Family on chert, the Kapilit Family on sandstone, the Tanjong Lipat Family on sandstone and mudstone and the Kumansi Family on mudstone.

Katai Family

The Katai Family of Orthic Acrisols (Figure 1-17) occurs on alluvium derived largely from basic and ultrabasic rocks. The soils have A, E, Bt horizon sequences. They are deep and well drained, with moderately fine-textured, sometimes stony, argillic horizons. Colours of the argillic horizons range from reddish brown to yellowish brown, the former being most common.

Exchangeable magnesium and exchangeable calcium levels are often medium to high and base saturation figures are close to 50% so that some of these soils are transitioned to Orthic Luvisols of the Numatoi Family. Cation exchange capacities are mostly between 10 and 20 meq% with higher values in the surface horizons; pH values range from 5 to 6. (Profile Ao 1).

Paliu Family

Orthic Acrisols of the Paliu Family (Figure 1-17) are formed on terraces of alluvium, which is generally medium to fine in texture and may contain pebbles. The soils are well to moderately well drained, with A, E Bt horizon sequences.

Of the reported profiles about 60% have moderately fine-textured argillic horizons; about 30% have medium textures and less than 10% have fine textures. Clay contents greater than 50% are very rare. The argillic horizons are commonly strong brown to yellowish red in colour, but vary from reddish brown to yellowish brown.

Cation exchange capacities are generally low and the CEC/100g clay of the B horizons is sometimes below 24 meq% indicating a transition to Orthic Ferralsols of the Benuou Family. Base saturation figures for the subsurface horizons are nearly all less than 20%. The soils are strongly acid, but there is often a slight increase of pH with depth. Kaolinite is most frequently the dominant mineral of the clay size fraction, with minor amounts of vermiculite and illite and varying amounts of quartz. (Profiles Ao 2, 3 and 4) (Plates 1-5 and 12)

Kinabutan Family

The Kinabutan Family (Figure 1-18) is comprised of Orthic Acrisols, which occur on basic and intermediate rocks, on low hills and ridges with slopes mainly between 10 and 20°. All of the reported profiles are well drained, but it is possible that moderately well drained ones may also occur. They are mainly deep with A, E, Bt horizon sequences; moderately deep profiles have C horizons within 125 cm (50 in) of the surface. The argillic horizons are mainly moderately fine or fine in texture, with strong brown to yellowish red or yellowish brown colours. None of the described profiles contain more than a few stones in the argillic or upper horizons, but stones increase with depth and stony BC horizons often occur; concretions have also been reported.

The cation exchange capacities of the argillic horizons are mostly in the 10-25 meq% range, but both higher and lower values have also been reported and a few argillic horizons have CEC/100g clay values of below 16 meq%. Base saturation figures are variable and some soils with high values are intergrades to Orthic Luvisols of the Kobovan-Family. Cation exchange capacities and base saturation values are usually highest in the surface horizons and pH value range from 4.5-5.5 (Profile Ao 5).

Dagat Family

The Dagat Family (Figure 1-18) comprises Orthic Acrisols on tuffaceous rocks. It occurs mainly on low hills with slopes of 10 to 20°. The soils are well drained and have fine-textured argillic horizons; clay contents may be as high as 60%. The argillic horizons are mainly strong brown to yellowish red, or red in colour. The soils are often stony and generally have horizons of weathering tuff or tuffite within 125 cm (50 in) of the surface.

The cation exchange capacities of these soils are high to very high, because of the high clay contents and the dominance of vermiculite with traces of illite. The levels of exchangeable cations are variable; magnesium tends to be high or very high, but calcium is mostly low, except in the surface horizons. Base saturation figures are generally low and pH values are mostly in the 4-5 range. (Profile Ao 6).

Mensuli Family

This family comprises Orthic Acrisols developed on chert. Only 1 profile has been reported; this is well drained with a fine-textured yellowish red argillic horizons. The cation exchange capacities and base saturation values are low, except in the surface horizon, which also has higher levels of exchangeable cations. The soil pH ranges from 4.5 to 5.0 (Profile Ao 7).

Kumansi, Tanjong Lipat and Kapilit Families

These 3 families of Orthic Acrisols all have varying proportions of sandstone and mudstone as their parent materials. Since it has proved extremely difficult to be certain of the precise nature of the parent material, the families are separated by using the clay content of the argillic horizon; soils with more than 40% clay, which are derived largely from mudstone, are included in the Kumansi Family; soils with 25-40% clay are included in the Tanjong Lipat Family and soils with argillic horizons containing less than 25% clay, which are largely derived from sandstone, are included in the Kapilit Family.

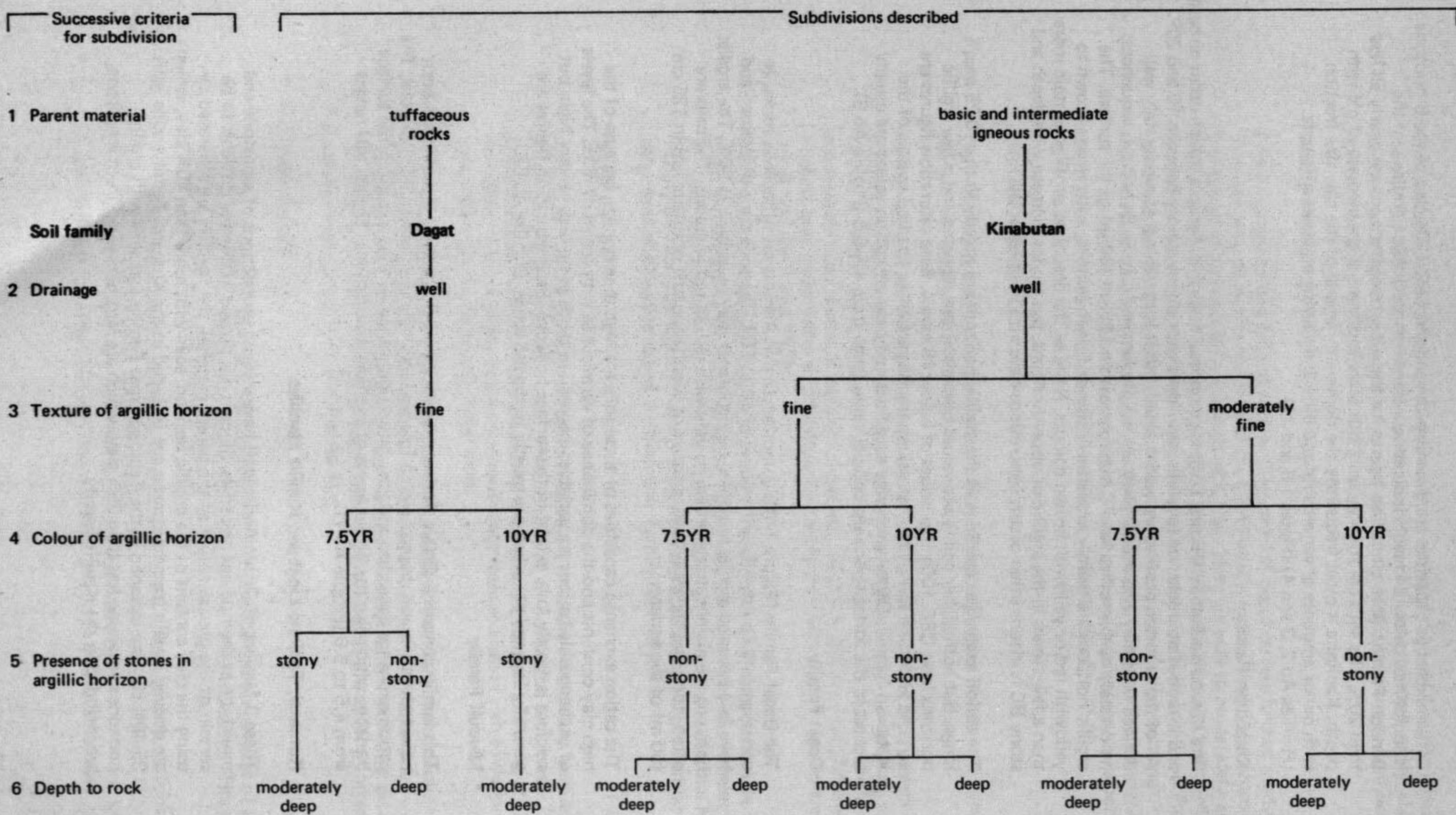


FIGURE 1-18 Orthic Acrisols on basic and intermediate igneous rocks and tuffaceous rocks: criteria for subdivision and subdivisions described

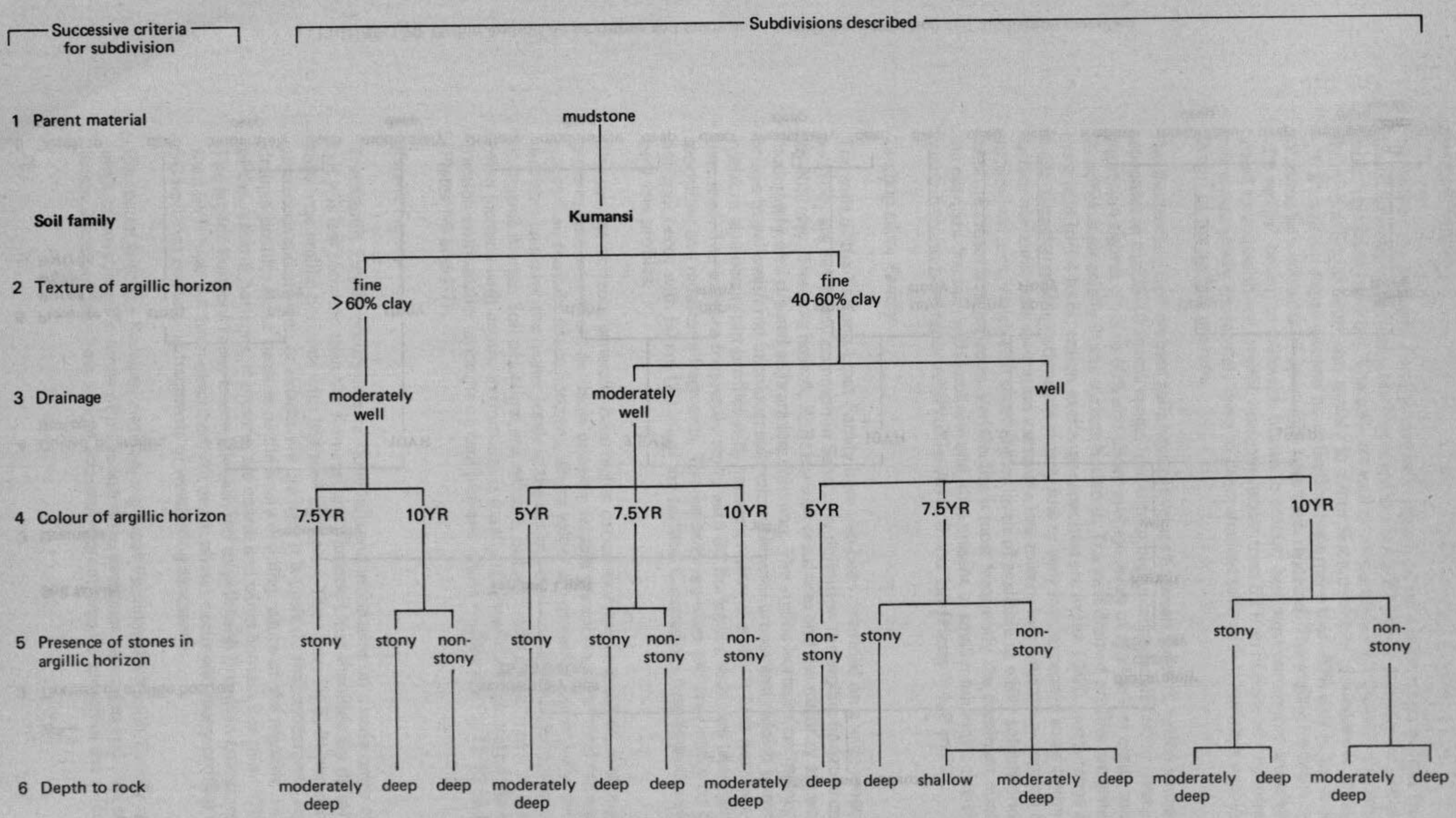


FIGURE 1-19 Orthic Acrisols on mudstone: criteria for subdivision and subdivisions described

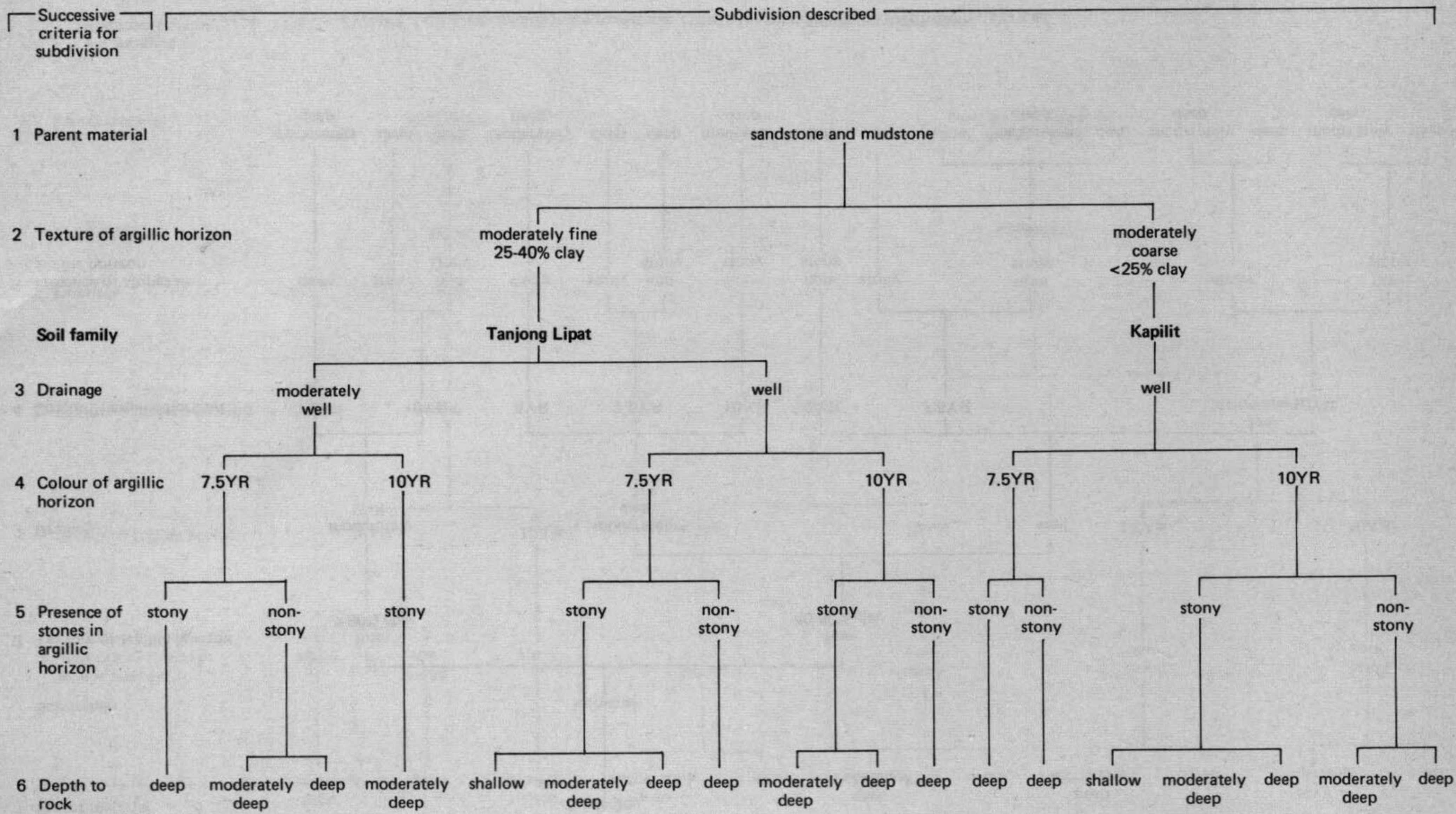


FIGURE 1-20 Orthic Acrisols on sandstone and mudstone: criteria for subdivision and subdivision described

Kumansi Family

The soils of the Kumansi Family have been described on a wide range of sites from low hills to mountains; typically the slopes are in the 10-20° range but some much steeper slopes have been reported. The soils are well or moderately well drained, the latter having mottling at depth due mainly to minor fluctuations of groundwater. They have A, E Bt horizon sequences and by definition have more than 40% clay in the argillic horizons; clay contents of up to 65% have been reported. The argillic horizons range from reddish brown to yellowish brown in colour, but most commonly are strong brown to yellowish red; argillic horizons redder than 5YR in hue are not common. The soils are generally moderately deep to deep; shallow soils with C horizons within 50 cm (20 in) of the surface are rare.

The moderately well drained soils have pH values between 5 and 6, cation exchange capacities in the 25-30 meq% range, medium to high exchangeable cation levels, base saturation figures close to 50% and above average levels of available or easily soluble phosphorus especially in the surface horizons. The well drained profiles are generally more acid (pH 4 to 5); cation exchange capacities are in the 10-20 meq% range and levels of exchangeable cations are mostly low or very low, except in some humus-rich surface horizons; base saturation values are low to very low with the exception of some surface horizons, which also show higher levels of available or easily soluble phosphorus than the subsurface horizons. Vermiculite is most frequently the dominant mineral of the clay size fraction with kaolinite and illite present in smaller amounts; clay-size quartz has also been reported (Profiles Ao 8, 9 and 10) (Plates 1-4, 8 and 9).

Tanjong Lipat Family

The soils of the Tanjong Lipat Family have also been described on a wide range of sites and they are extremely common in Sabah. By definition the argillic horizons contain 25-40% clay. The soils have A, E, Bt horizon sequences and the majority are well drained; moderately well drained soils are less common. The argillic horizons are mainly strong brown to yellowish red in colour; soils with yellowish brown and reddish brown argillic horizons also occur, but profiles with horizons redder than 5YR have not been described. The soils are frequently stony with BC horizons containing weathering sandstone and mudstone fragments. The majority are deep and only rarely do C horizons occur with 50 cm (20 in) of the surface. Concretions have been described in very few profiles.

The surface horizons generally have higher cation exchange capacities, exchangeable cations, base saturation, available or easily soluble phosphorus and total nitrogen values than the subsurface horizons, where values are generally low or very low. The probable cause for the higher levels in the surface horizons is the slight accumulation of organic matter. Soil pH values are variable, but generally range from 4 to 5 and often increase with depth. Vermiculite is usually the dominant mineral of the clay size fraction with smaller amounts of kaolinite and illite (Profiles Ao 11, 12 13 and 14) (Plates 1-6 and 1-7).

Kapilit Family

The Kapilit Family occurs on sandstone hills and mountains on a wide range of slopes, but it is less common than the Kumansi and Tanjong Lipat Families. By definition the soils have argillic horizons with less than 25% clay. They have A, E, Bt horizon sequences and are well or excessively drained; it is unlikely that moderately well drained profiles occur because of the freely draining nature of the regolith. Textures of the A and E horizons, if present, are coarse and often contain less than 10% clay. The argillic horizons range from yellowish red to yellowish brown in colour; redder than 5YR have not been described. All depth phases occur and many profiles have BC horizons containing fragments of weathering sandstone.

Compared with the Kumansi and Tanjong Lipat Families the Kapilit Family is the most impoverished in terms of plant nutrients, exchange capacities and base saturation levels. Some profiles show a slight accumulation of organic carbon in the surface horizon and associated with this there are higher cation exchange capacities, exchangeable cations, easily soluble or available phosphorus and total nitrogen levels. Vermiculite is usually the dominant mineral of the clay size fraction with kaolinite in varying amounts; illite and quartz have never been reported in more than trace amounts (Profiles Ao 15 and 16).

Luvisols

GENERAL DESCRIPTION

Definition: Luvisols are soils which have an argillic B horizon in which the base saturation is more than 50% (by $NH_4\ OA_c$) throughout.

Luvisols ideally have A, E and BT horizon sequences. All profiles have A and Bt horizons, but clearly defined E horizons are rare and are either completely lacking or replaced by transition AB or EB horizons. Moderately deep and shallow phases have C horizons within 125 cm (50 in) and 50 cm (20 in) respectively. The argillic horizons are normally fine or moderately fine in texture. Base saturation values range from 50 to 100% and contents of exchangeable magnesium in particular are often high or very high. In soils developed on limestone and in some soils found on basic rocks exchangeable calcium is the main cause of high base saturation. The majority of Luvisols have medium to high cation exchange capacities and are acid in reaction with pH values ranging from 5.0 – 6.5. The doubts expressed in the section on Acrisols, concerning the problems of identifying argillic horizons, also apply to Luvisols.

Gleyic, Calcic, Ferric, Chromic and Orthic Luvisols have been described in Sabah. These units have been separated into families on the basis of parent materials (Table 1-9) and have been further subdivided using drainage, texture, colour, depth and stoniness as criteria. These criteria are the same as those used in the subdivision of Acrisols, with the CEC/100g clay used as an additional criterion in the definition of Ferric Luvisols.

GLEYIC LUVISOLS

Definition: Gleyic Luvisols are Luvisols having a gleyic horizon.

The gleyic horizons are caused either by fluctuations of groundwater or by slowly percolating surface water. Soils with fluctuating groundwater are either poorly or imperfectly drained. Poorly drained soils have gleyic horizons above 50 cm (20 in) and imperfectly drained soils have gleyic horizons between 50 and 125 cm (20-50 in); in the former the argillic horizons are also gleyic but in the latter only the lower argillic horizons are gleyic. In soils affected by slowly percolating surface water the gleyic horizons are close to the surface and both A and E horizons, if present, may be gleyic; the argillic horizon may also be gleyic.

TABLE 1-9 Luvisols: soil families and associations in which they commonly occur

Soil unit	Parent material	Family	Association
Gleyic Luvisol	Alluvium derived from basic and ultrabasic rocks	Nangoh	Binalik
	Calcareous alluvium	Lungpatau	Tungku
	Alluvium	Buran	Kinabatangan Sapi Tuaran Karamuak Lungmanis Silabukan Rumidi Kalabakan Binkor Tengah Nipah

TABLE 1-9 (continued)

Soil unit	Parent material	Family	Association
Gleyic Luvisol (continued)	Mudstone	Lunparai	Lungmanis Silabukan Rumidi
Calcic Luvisol	Limestone	Semporna	Lungmanis Silabukan Rumidi Semporna Gomantong
Ferric Luvisol	Alluvium derived from basic and ultrabasic rocks	Pantagaluang	Binalik
	Basic igneous rocks	Besar	Tinagat
	Mudstone	Lumerau	Lungmanis Silabukan Rumidi Kalabakan
Chromic Luvisol	Alluvium derived from basic and ultrabasic rocks	Mangkap	Binalik
	Calcareous alluvium	Terang	Tungku
	Alluvium	Sabor	Karamuak
	Ultrabasic igneous rocks	Malawali	Bidu Bidu Malubok
	Basic igneous rocks	Beeston	Mentapok
	Tuffaceous rocks	Libong	Dagat Gumpal Kennedy Bay
	Limestone	Tegupi	Semporna
Orthic Luvisol	Alluvium derived from basic and ultrabasic rocks	Numatoi	Karamuak Tapang Binalik
	Alluvium	Darau	Tuaran Karamuak
	Ultrabasic igneous rocks	Tingkayu	Bidu Bidu Malubok Bang Gumpal
	Basic igneous rocks	Kobovan	Mentapok Malubok Beruang Sipit
	Tuffaceous rocks	Talid	Gumpal Kretam Sipit Bang Rumidi
	Mudstone	Lumpongon	Lungmanis Silabukan Rumidi

Four families have been recognised, namely the Nangoh Family on alluvium derived largely from ultrabasic rocks, the Lungpatau Family on calcareous alluvium, the Buran Family on undifferentiated alluvium and the Lunparai Family on mudstone (Figure 1-21).

Nangoh Family

Gleyic Luvisols of the Nangoh Family are developed on alluvium derived predominantly from ultrabasic rocks and are found on alluvial fans in minor valleys radiating from ultrabasic mountains. Only one profile (Profile Lg 1) has been described. This is poorly drained due to groundwater fluctuations and has an olive grey argillic horizon with moderately fine texture; hard black concretions occur throughout the profile. Cation exchange capacities and exchangeable calcium and potassium levels are low; the soils are neutral in reaction.

Lungpatau Family

Gleyic Luvisols of the Lungpatau Family are formed on calcareous alluvium on a low terrace bordering coastal lagoons in the Dent Peninsula. The alluvium overlies coral and lower horizons contain coral fragments. One profile only has been described (Profile Lg 2); this is poorly drained and moderately deep with coral at 75 cm (30 in). The argillic horizons contain 65-75% clay.

The soils of this family are chemically distinctive from other Gleyic Luvisols and are closely related to Calcic Luvisols of the Semporna Family. Cation exchange capacities are very high (>50 meq%) and exchangeable calcium, magnesium and sodium are all very high; calcium is dominant and is the main reason for the saturation of the exchange complex. Exchangeable potassium levels are above average for Luvisols. The soils are alkaline with pH values in the 7.5 to 8.0 range.

Buran Family

Gleyic Luvisols of the Buran family are formed on undifferentiated alluvium. They are widespread throughout the state on the floodplains of major rivers such as the Kinabatangan, Segama, Labuk, Sugut and Padas and also on floodplains of smaller rivers; they occur less commonly on low terraces of interior valleys. Gleyic horizons are mostly caused by fluctuations of groundwater and both poorly and imperfectly drained soils occur; gleyic horizons, which are caused by slowly percolating surface water, are associated particularly with wet rice cultivation. The poorly drained soils are deep with A, Eg, Btg and Cg horizon sequences; the Eg horizon, however, is often absent. Buried organic horizons and strata of contrasting textures may occur. The argillic horizon is generally fine or moderately fine in texture with colours ranging from greyish brown to light grey and with yellowish brown to yellowish red mottles. Manganese and iron concretions occur in some profiles particularly in the lower horizons of those with moderately fine textures. The imperfectly drained soils are deep with A, E, Bt or Btg and Cg horizons. The argillic horizon is either fine- or moderately fine-tectured and yellowish brown in colour with light yellowish brown or grey mottles; manganese concretions may be present. Soils with surface water gleying have Apg and Bt horizons; the argillic horizons have moderately fine textures and strong brown to yellowish red colours.

The majority of these soils have cation exchange capacities ranging from 10-20 meq%, high magnesium, medium potassium, low exchangeable calcium and sodium values and acid or strongly acid reactions. The few determinations of clay minerals that have been made show that either illite, vermiculite or kaolinite are dominant (Profiles Lg 3, 4 and 5).

Lunparai Family

Gleyic Luvisols of the Lunparai Family are formed on low hills of mudstone and shales, which locally may be bentonitic or tuffaceous.

Poorly and imperfectly drained soils have been described and in both the drainage imperfection appears to be caused by slow percolation of surface water through the fine textured regolith. Poorly drained profiles have A, E and Btg horizons; they are deep and fine-textured. The argillic horizons have clay contents which range from 40 to 55% and light grey or greenish grey colours with yellowish brown or strong brown mottles.

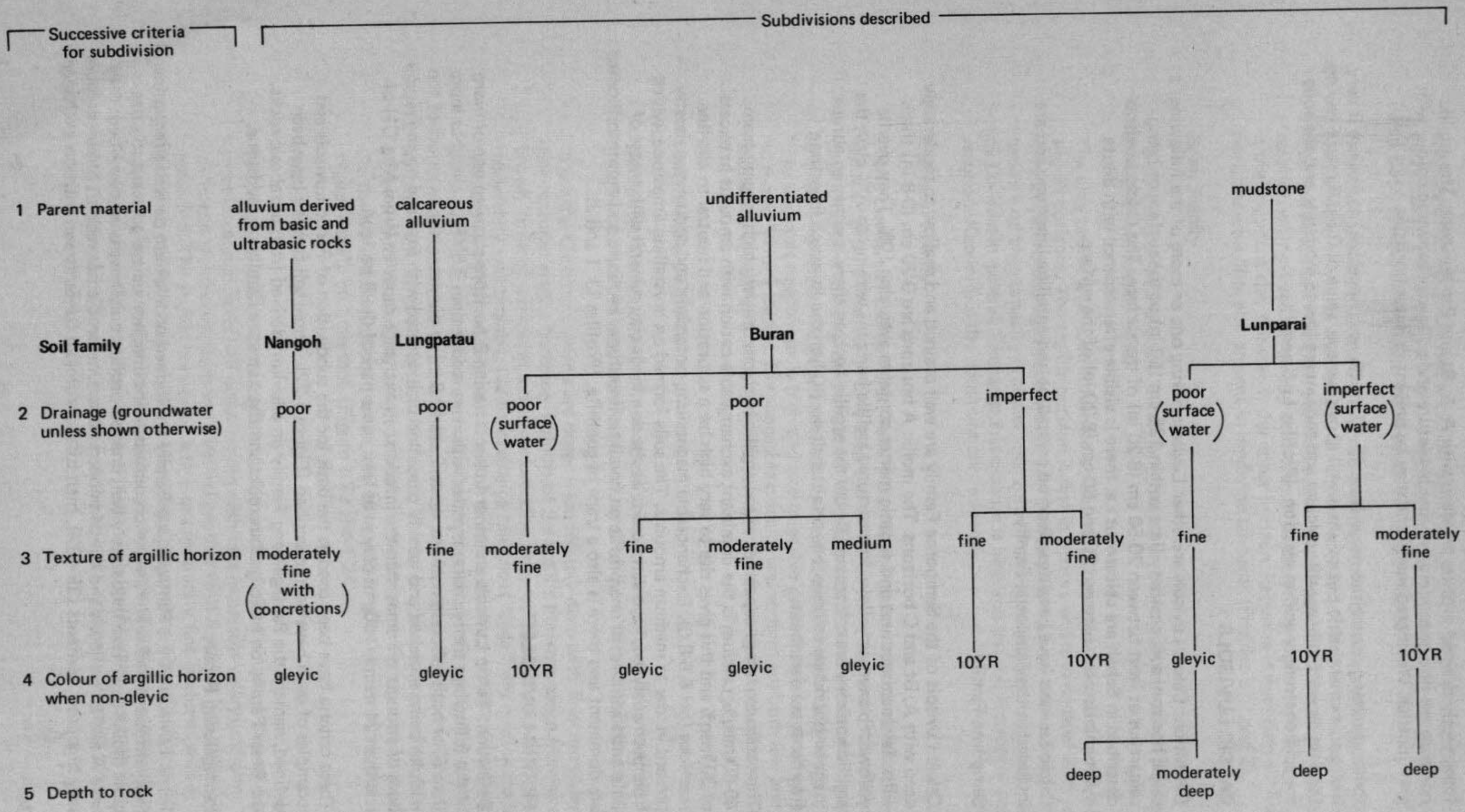


FIGURE 1-21 Gleyic Luvisols: criteria for subdivision and subdivisions described

Imperfectly drained profiles are deep with A, E, Bt and Btg horizons. The argillic horizons are fine or moderately fine in texture and yellowish brown in colour with grey mottles. Weathered mudstone may be present in lower horizons.

Cation exchange capacities range from 15-40 meq%, exchangeable magnesium is very high and exchangeable potassium is well above average, value of 0.5-0.6 meq% having been reported. Exchangeable calcium and sodium are low to moderate and the soils are acid or strongly acid in reaction. (Profiles Lg 6 and 7).

CALCIC LUVISOLS

Definition: Calcic Luvisols are other Luvisols having one or more of the following: a calcic horizon; soft powdery lime within 125 cm (50 in) of the surface or being calcareous at least between 20-50 cm (8-20 in) of the surface. The Calcic Luvisols described in Sabah are calcareous i.e. there is visible effervescence with dilute hydrochloric acid, between 20 and 50 cm (8-20 in) of the surface.

Calcic Luvisols have been described on crystalline and coralline limestone and are included in the Semporna Family.

Semporna Family

Calcic Luvisols of the Semporna Family are well drained and shallow to moderately deep with A, Bt and C horizons. The mollic A horizons are 0-20 cm (0-8 in) thick with clay loam textures and organic matter contents averaging 10%. They overlie yellowish brown or yellow, fine-textured argillic horizons with up to 70% clay; the argillic horizons are calcareous. Below the argillic horizon there is either an abrupt irregular boundary to limestone or a transition BC horizon in which limestone fragments are dominant.

The cation exchange capacities of the argillic horizons are very high ranging from 40-60 meq%; calcium is the dominant exchangeable cation with amounts in excess of 30 meq% and this gives rise to very high base saturation and neutral to alkaline reactions (pH 6.5-8.0). Exchangeable magnesium, potassium and sodium are mostly present in low to medium amounts. The soils formed on crystalline limestone, which have been analysed, have vermiculite as the dominant clay mineral with traces of illite and kaolinite; in one profile on coralline limestone, kaolinite and montmorillonite are dominant and there is also a trace of goethite. (Profiles Lk 1 and 2).

FERRIC LUVISOLS

Definition: Ferric Luvisols are other Luvisols having B horizons showing one or more of the following: many coarse mottles with hues redder than 7.5YR or chromas more than 5, or both; discrete nodules, up to 2 cm (0.8 in) in diameter, the exteriors of the nodules being enriched and weakly cemented or indurated with iron and having redder hues or stronger chromas than the interiors; an exchange capacity (from Nh_4 C1) of less than 24 meq%/100g of clay in at least some part of the B horizon.

These criteria have been used as the basis for the subdivision of Ferric Luvisols and examples of each have been described (Figure 1-22). Three soil families have been defined, namely the Pantagaluang Family on alluvium derived from ultrabasic rocks, the Besar Family on basic igneous rocks and the Lumerau Family on mudstone.

Pantagaluang Family

Ferric Luvisols of the Pantagaluang Family are formed on alluvium derived predominantly from ultrabasic rocks. They occur on outwash fans in minor valleys adjacent to ultra-basic mountains. Two moderately well drained profiles only have been described; they have A and Bt horizons and contain concretions. One profile has reddish brown colours, very high iron contents (35-40%), high total chromium contents and a cation exchange capacity of less than 24 meq% in the argillic horizon; it is closely related to Orthic Ferralsols of the Nobusu Family. The other profile has dark yellowish brown colours. In both, the argillic horizons are moderately fine-textured.

Cation exchange capacities are low and exchangeable calcium, potassium and sodium contents are very low. Exchangeable magnesium is lower than in most Luvisols with reported values of 2-7 meq%; base saturation is between 50-70% and soils are acid in reaction with pH values ranging from 5 to 6. In the only profile analysed vermiculite is the dominant clay mineral in the upper horizon; kaolinite is dominant in the lower horizons with illite also present in moderate amounts (Profiles Lf 1 and 2).

Besar Family

Ferric Luvisols of the Besar Family are formed on basic igneous rocks. (See Besar sub-family in Paton, 1963).

The only profile described is formed on dolerite; it is deep and well drained with A and Bt horizons. The argillic horizon is fine in texture and is variegated with red, reddish yellow and light yellowish brown colours; there are no concretions. The cation exchange capacity is higher than other Ferric Luvisols and is more typical of Luvisols in general. Exchangeable calcium is high and the soil is strongly acid in reaction. Kaolinite is the dominant clay mineral.

Lumerau Family

Ferric Luvisols of the Lumerau Family are formed on low mudstone hills. The only reported profile (Profile Lf 3) is deep and well drained with A and Bt horizons. The argillic horizon has clay contentsof 60-70%,yellowish brown matrix colours, is mottled and has a cation exchange capacity which is less than 24 meq%/100g of clay. Exchangeable magnesium is high and exchangeable potassium is unusually high (0.6 meq %) for Luvisols. Exchangeable calcium and sodium are both low and base saturation is near 50% indicating transition to Ferric Acrisols of the Batang Family.

CHROMIC LUVISOLS

Definition: Chromic Luvisols are other Luvisols having strong brown to red B Horizons (rubbed soil has a hue of 7.5YR and a chroma of more than 4, or has a redder hue).

In general Chromic Luvisols are deep or moderately deep with fine- or moderately fine-textured argillic horizons. Colours of the argillic horizons range from strong brown, through yellowish red to dark reddish brown. The soils are well drained to moderately well drained. Cation exchange capacities range from medium to high and with the exception of soils developed on calcareous parent materials, exchangeable magnesium is the dominant exchangeable cation. Most soils are acid in reaction. Seven soil families have been distinguished: the Mangkap Family on alluvium derived from ultrabasic rocks, the Terang Family on calcareous alluvium, the Sabor Family on undifferentiated alluvium, the Malawali Family on ultrabasic rocks, the Beeston Family on basic rocks, the Libong Family on tuffaceous rocks and the Tegupi Family on limestone (Figure 1-23 and 1-24).

Mangkap Family

Chromic Luvisols of the Mangkap Family are formed on alluvium derived predominantly from ultrabasic rocks and occur on outwash fans in narrow valleys radiating from ultrabasic mountains. Deep well drained profiles with A and Bt horizons have been described. The argillic horizons are fine- or moderately fine-textured with strong brown or reddish brown colours. Manganese concretions normally occur. These soils have low to medium cation exchange capacities and variable amounts of exchangeable calcium, potassium and magnesium; exchangeable magnesium is very high causing high base saturation, but the soils are acid with reported pH values ranging from 5.7-6.2. (Profile Lc 1).

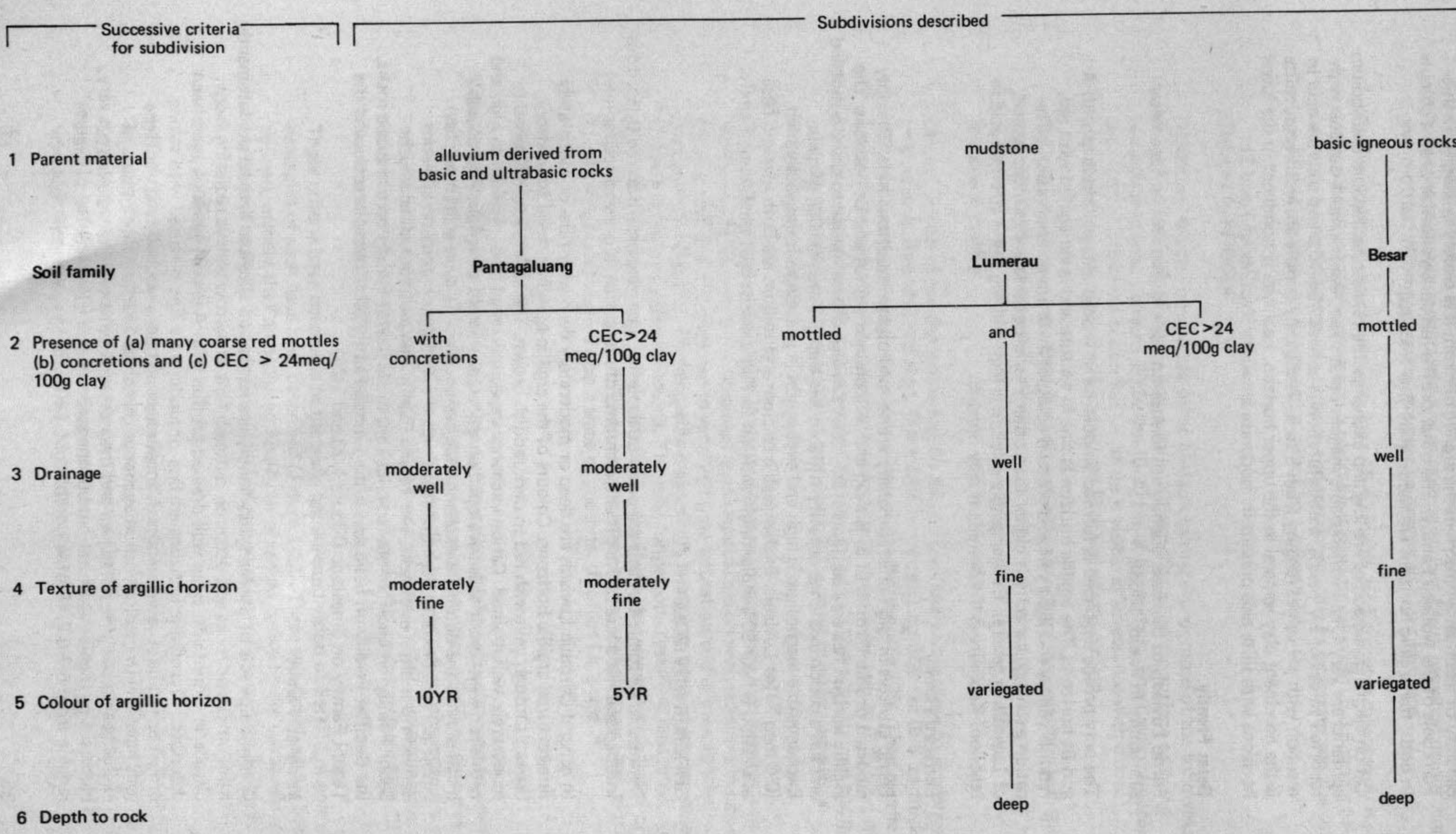


FIGURE 1-22 Ferric Luvisols: criteria for subdivision and subdivisions described

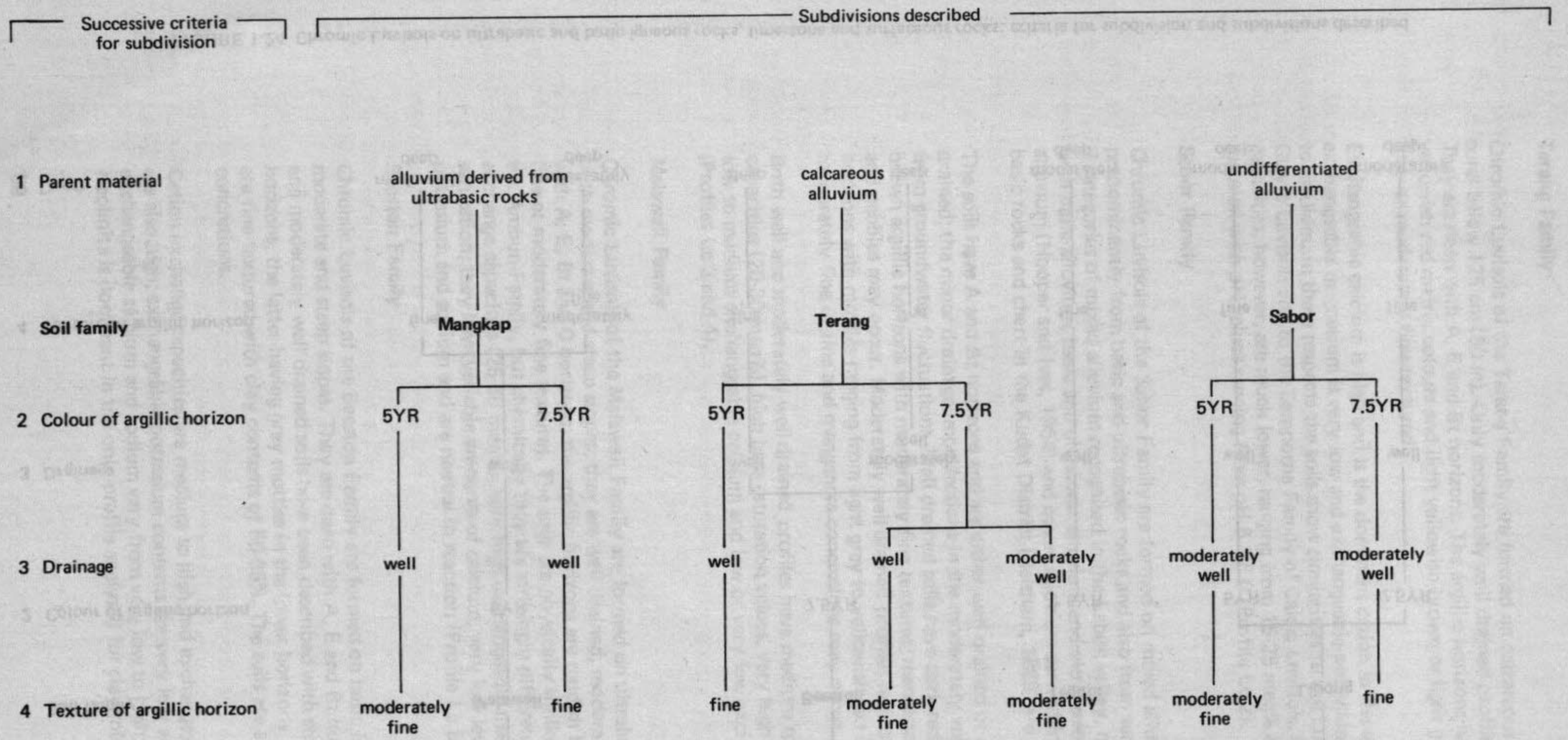


FIGURE 1-23 Chromic Luvisols on alluvium: criteria for subdivision and subdivisions described

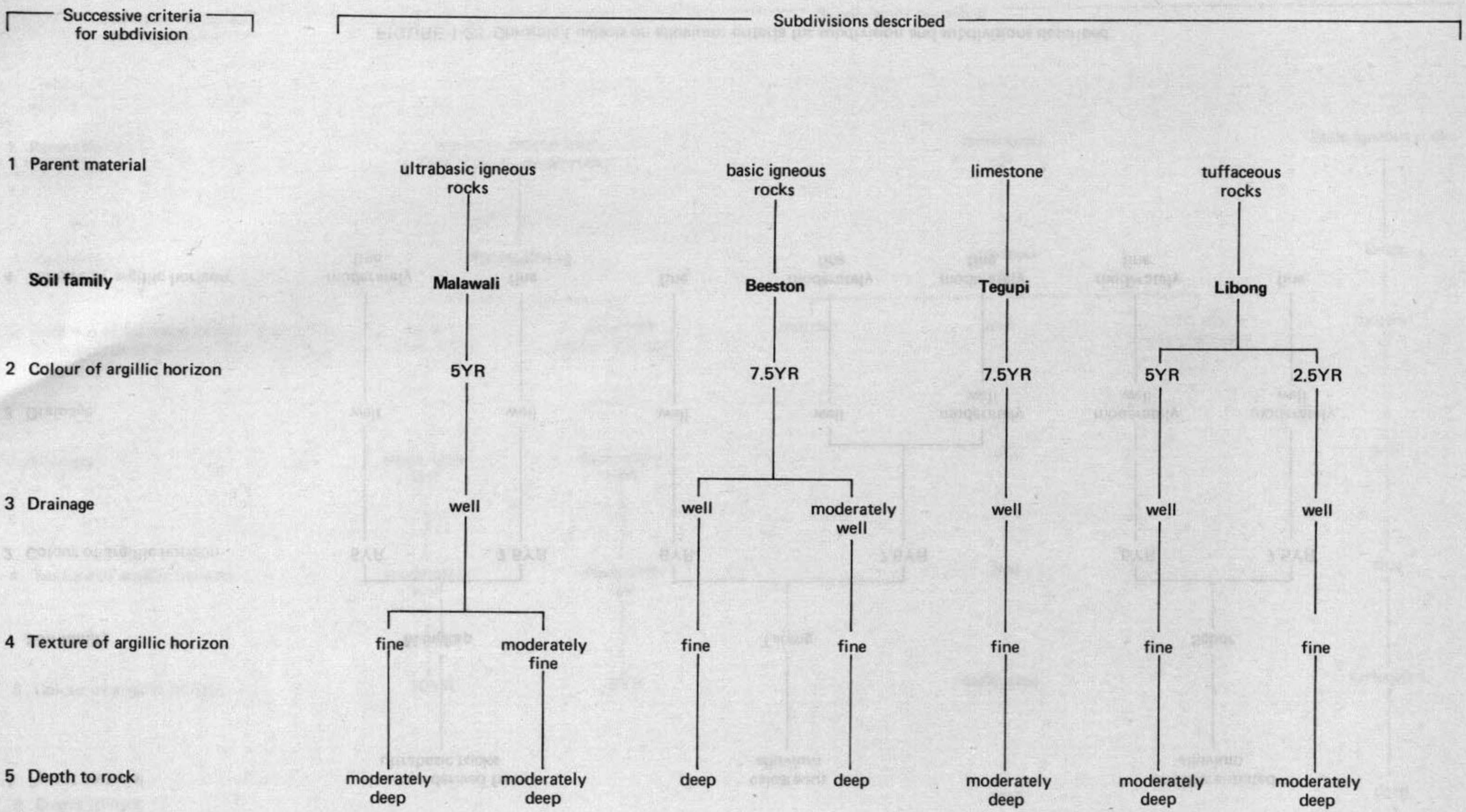


FIGURE 1-24 Chromic Luvisols on ultrabasic and basic igneous rocks, limestone and tuffaceous rocks: criteria for subdivision and subdivisions described

Terang Family

Chromic Luvisols of the Terang Family are formed on calcareous alluvium overlying coral below 125 cm (50 in). Only moderately well drained profiles have been described. They are deep with A, E and Bt horizons. The argillic horizons have strong brown or yellowish red matrix colours and light yellowish brown or light grey mottles; they are fine- or moderately fine-textured.

Exchangeable calcium is high and is the dominant cation in the exchange complex; exchangeable magnesium is very low and exchangeable potassium and sodium are low to medium. In these respects the soils show similarities to the Lungpatau Family of Gleyic Luvisols and to the Semporna Family of Calcic Luvisols. Cation exchange capacities, however, are much lower, ranging from 15-25 meq% and soils are acid in reaction with pH values ranging from pH 5.3-6.0 (Profile Lc 2).

Sabor Family

Chromic Luvisols of the Sabor Family are formed on mixed alluvium derived predominantly from basic and ultrabasic rocks and also from sedimentary rocks. The 3 categories of mixed alluvium recognised in the Labuk valley, namely sedimentary with basic alluvium, basic and ultrabasic alluvium and ultrabasic with sedimentary alluvium (Hooper and Ives, 1964) and mixed alluvium derived from ultrabasic and basic rocks and chert in the Kudat District (Belsham, 1969) are all included.

The soils have A and Bt horizons and are either well drained or moderately well drained; the minor drainage imperfections in the moderately well drained soils result from groundwater fluctuations. Well drained soils have dark reddish brown or strong brown argillic horizons with moderately fine textures; manganese stains or concretions and pebbles may occur. Moderately well drained profiles have strong brown argillic horizons with mottles ranging from light grey to yellowish red in colour; textures are moderately fine or fine and manganese concretions may occur.

Both well and moderately well drained profiles have medium to high cation exchange capacities (20-30 meq%), high base saturation values, very high exchangeable magnesium, low to medium exchangeable calcium and low or very low exchangeable potassium. (Profiles Lc 3 and 4).

Malawali Family

Chromic Luvisols of the Malawali Family are formed on ultrabasic igneous rocks on both moderate and steep slopes; they are well drained, moderately deep and often stony, with A, E, Bt and C horizons; the argillic horizons are reddish brown in colour with fine or moderately fine textures. The soils are physically similar to Orthic Ferralsols of the Ambun Family, but chemically they are strikingly different with high cation exchange capacities (25-60 meq%), very high exchangeable magnesium and high base saturation; they have variable amounts of calcium, very low levels of exchangeable potassium and sodium and are neutral in reaction (Profile Lc 5).

Beeston Family

Chromic Luvisols of the Beeston Family are formed on basic igneous rocks on both moderate and steep slopes. They are deep with A, E and Bt horizons. Well drained and moderately well drained soils have been described with strong brown argillic horizons, the latter having grey mottles in the lower horizons. The argillic horizons are fine-textured with clay contents of 50-65%. The soils are stony and may contain concretions.

Cation exchange capacities are medium to high and exchangeable magnesium contents are also high; exchangeable potassium contents are very low and contents of both exchangeable calcium and sodium vary from very low to high; the soils are acid. Kaolinite is dominant in the only profile analysed for clay minerals. (Profile Lc 6).

Libong Family

Chromic Luvisols of the Libong Family occur on low hills formed of tuffaceous rocks, variously described as tuffite, tuff, basic sandstone, sandstone and mudstone. The soils are deep or moderately deep with A, E, and Bt horizons underlain by C horizons in the latter; they are well or moderately well drained. The argillic horizons are yellowish red to red with grey mottles in the moderately well drained profiles; they are fine-textured with 40-50% clay.

Cation exchange capacities are medium to very high and exchangeable magnesium contents are also very high; exchangeable calcium, potassium and sodium contents range from low to very high. The soils are acid or strongly acid. Clay mineral determinations show that in one profile montmorillonite is dominant with a trace of vermiculite, and in another vermiculite is dominant with moderate amounts of kaolinite and traces of halloysite, illite and montmorillonite.

Tegupi Family

Chromic Luvisols of the Tegupi Family are formed on low limestone hills. The only profile which has been described is moderately deep and well drained with A, Bt and C horizons. The argillic horizon is strong brown with reddish brown mottles and fine textures.

Calcium is the dominant cation in the exchange complex; contents of exchangeable potassium, sodium and magnesium are all low. Cation exchange capacities are medium and the soils are acid in reaction. (Profile Lc 8).

ORTHIC LUVISOLS

Orthic Luvisols are Luvisols which lack the properties diagnostic of Gleyic, Calcic, Ferric and Chromic Luvisols. Six soil families have been recognised in Sabah: the Numatoi Family on alluvium derived from basic and ultrabasic rocks, the Darau Family on undifferentiated alluvium, the Tingkayu Family on ultrabasic igneous rocks, the Kobovan Family on basic igneous rocks, the Talid Family on tuffaceous rocks and the Lumpongon Family on mudstone (Figure 1-25).

Numatoi Family

Orthic Luvisols of the Numatoi Family are formed on mixed alluvium derived predominantly from basic and ultrabasic rocks. They occur on valley floors and terraces of minor valleys in the vicinity of basic and ultrabasic mountains. The soils have A, E and Bt horizons and are well or moderately well drained, the latter having grey mottles in the lower horizons due to groundwater fluctuations. The argillic horizons are fine or moderately fine in texture, with colours ranging from dark brown through yellowish brown to greyish brown; the lower horizons are often stony.

The majority of soils have medium to high cation exchange capacities with very high exchangeable magnesium levels; exchangeable calcium is generally low and exchangeable potassium and sodium are low to very low. The soils are acid to neutral in reaction. In the only profile analysed for clay minerals, kaolinite was dominant and montmorillonite was also present. (Profile Lo 1).

Darau Family

Orthic Luvisols of the Darau Family occur on undifferentiated alluvium on the floodplains and terraces of minor valleys. Moderately well drained profiles have only been described. They have A, E and Bt horizons with dark brown to yellowish brown matrix colours and pale brown or grey mottles in lower horizons. The argillic horizons have moderately fine textures. Stones and, less commonly, concretions may be present.

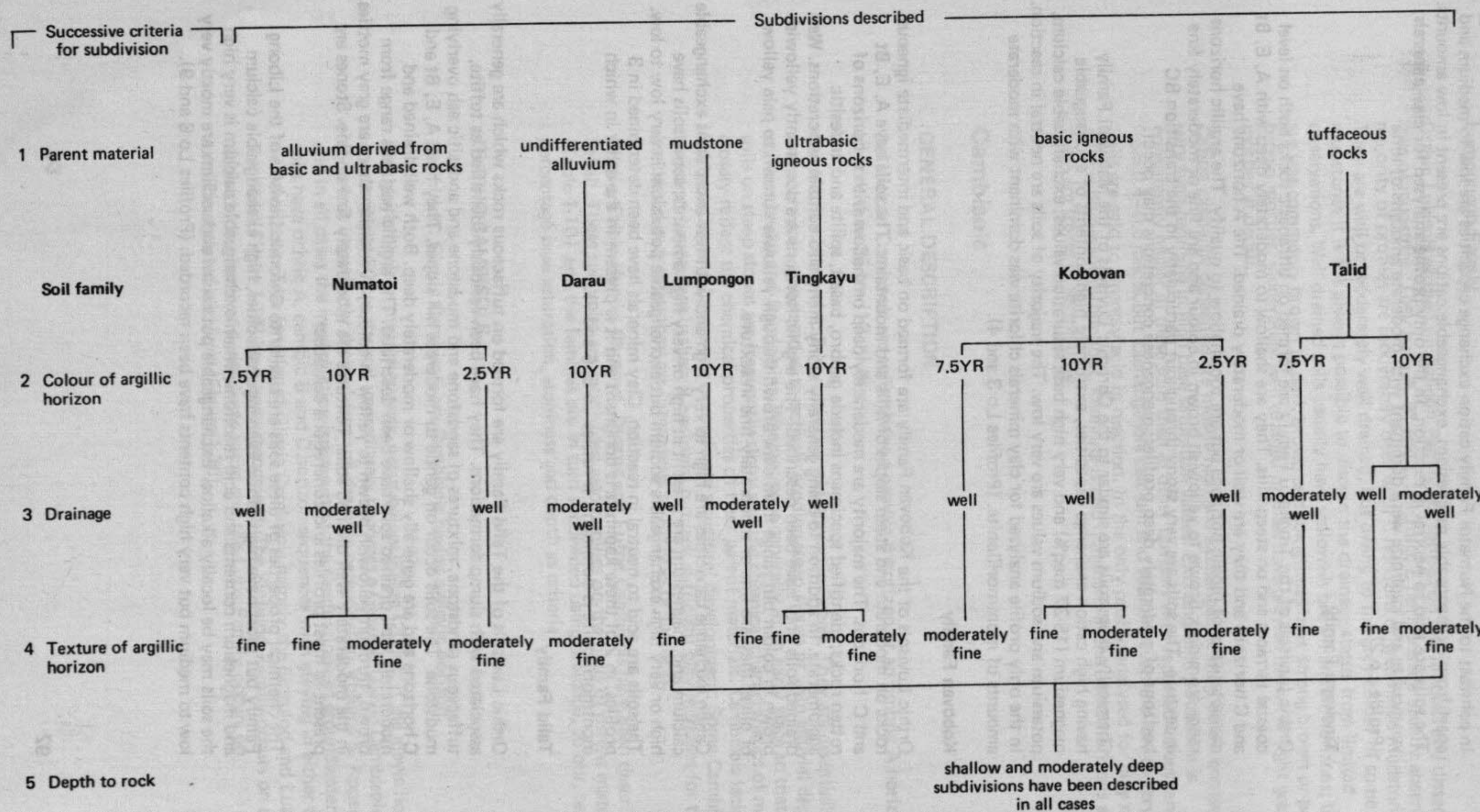


FIGURE 1-25 Orthic Luvisols: criteria for subdivision and subdivisions described

In contrast to the Numatoi Family cation exchange capacities are low to medium and apart from exchangeable magnesium, exchangeable cations are present in low amounts. The soils are acid to neutral in reaction. In the only profile analysed for clay minerals, vermiculite and kaolinite were dominant with moderate amounts of illite (Profile Lo 2).

Tingkayu Family

Orthic Luvisols of the Tingkayu Family are formed on ultrabasic rocks both on level coastal terraces and on steep hills. They are shallow to moderately deep with A, E, Bt and C horizons and they are well or moderately drained. The A horizons have characteristics of mollic horizons but are too shallow to qualify. The argillic horizons range from dark brown to yellowish brown in colour and are fine or moderately fine in texture. The soils are very stony throughout particularly in the transition BC horizons of moderately deep profiles; manganese concretions may occur.

Chemically these soils are similar to the Chromic Luvisols of the Malawali Family having high cation exchange capacities, extremely high contents of exchangeable magnesium (15-37 meq%) and very high base saturation values; exchangeable calcium, potassium and sodium values are very low. The majority of soils are neutral in reaction. In the only profile analysed for clay minerals chlorite was dominant with moderate amounts of montmorillonite. (Profiles Lo 3 and 4).

Kobovan Family

Orthic Luvisols of the Kobovan Family are formed on basic and intermediate igneous rocks on moderate and steep slopes of hills and mountains. The soils have A, E, Bt and C horizons. The majority are moderately deep or shallow with C horizons of rotten rocks; identified specimens include gabbro, basalt, spilite and andesitic agglomerate. In addition to being generally stony many also contain concretions. Well drained soils only have been described. The argillic horizons are dominantly yellowish brown in colour but range from dark brown through yellowish brown to pale yellow or olive; they are fine or moderately fine in texture.

Cation exchange capacities are high to very high and with few exceptions exchangeable calcium and magnesium are present in high or very high amounts; some soils have high or very high exchangeable sodium but exchangeable potassium is very low to low. The soils are acid to neutral in reaction. Clay minerals have been determined in 3 profiles; in 2 of these kaolinite is dominant and it is present in the other in which montmorillonite is dominant. (Profiles Lo 5, 6 and 7).

Talid Family

Orthic Luvisols of the Talid Family are formed on tuffaceous rocks which are generally associated with slump formations. They have been variously identified as tuffite, tuffaceous sandstone, mixtures of sandstone and mudstone and andesitic ash overlying mudstone. The soils occur on gentle to moderate hill slopes. They have A, E, Bt and C horizons and are generally shallow or moderately deep. Both well drained and moderately well drained soils have been described. The argillic horizons range from brown, through yellowish brown to yellow in colour; in addition there are grey mottles in the moderately well drained soils. Textures are moderately fine or fine. Stones are present in most profiles and concretions can occur.

The chemical properties of these soils are similar to Chromic Luvisols of the Libong Family but most have high cation exchange capacities, high exchangeable calcium and magnesium contents and acid reactions; when exchangeable calcium is very high the soils may be locally alkaline. Exchangeable potassium and sodium are mostly very low to medium but very high contents have been recorded. (Profiles Lo 8 and 9).

Lumpongon Family

Orthic Luvisols of the Lumpongon Family are formed on low hillocks and dissected hills of mudstone. They have A, Bt and C horizons; E horizons are usually absent. The majority of profiles are moderately deep with C horizons of weathered mudstone. They are well or moderately well drained, but owing to the grey colour of some mudstones it is not always possible to discern the drainage status from limited observations. Well drained soils usually have yellowish brown argillic horizons; they are less commonly brown to dark brown and sometimes have strong brown or pale brown mottles. Moderately well drained profiles have greyish brown or light grey mottles at depth.

Cation exchange capacities are mostly high and exchangeable magnesium contents are very high resulting in high base saturation values. Exchangeable potassium is consistently higher in these soils than in other Luvisols with reported values ranging from 0.4–0.6 meq%, but exchangeable calcium and sodium levels are low to very low. Soils are acid to strongly acid in reaction. In the only profile analysed for clay minerals illite is dominant throughout; kaolinite is also dominant in the upper horizons and there are traces of vermiculite.

Cambisols

GENERAL DESCRIPTION

Definition: Cambisols are soils having a cambic B horizon or an umbric A horizon which is more than 25 cm (10 in) thick.

Cambisols with cambic B horizons are widespread in Sabah. They are essentially immature soils associated with actively eroding steep slopes or with alluvial deposits on river levees and floodplains. Weathering is generally at an early stage so that the soils on steep slopes are frequently stony and the chemical characteristics of many closely reflect the chemical properties of their parent materials. Cambisols lack strong horizonation and have weak or moderate structural development. Some Cambisols, however, havecutans in their B horizons, but lack sufficient clay increases for these to be classed as argillic; they are intergrades to Acrisols or Luvisols.

Gleyic, Calcic, Humic, Chromic, Dystric and Eutric Cambisols have been described in Sabah. These soil units are subdivided into families on the basis of parent materials (Table 1-10) and the families are in turn subdivided using drainage, colour, texture, percentage base saturation, stoniness and depth as criteria.

GLEYIC CAMBISOLS

Definition: Gleyic Cambisols are Cambisols having a gleyic horizon.

The gleyic horizon must, however, occur below 50 cm (20 in); if the gleyic horizon occurs above 50 cm the soil immediately becomes a Gleysol. Gleyic Cambisols are therefore imperfectly drained (see soil drainage categories in Volume 5, Appendix 3) and in all cases the imperfection is a result of the fluctuations of groundwater. The soils have ochric A, cambic B and C horizon sequences with gleying in either the B or C horizons. Two families of Gleyic Cambisols namely the Sinsulod and Luba Families (Figure 1-26) have been recognised. The Sinsulod Family occurs on alluvium derived from basic and ultrabasic rocks and the Luba Family occurs on undifferentiated alluvium (Figure 1-26).

TABLE 1-10 Cambisols: soil families and associations in which they commonly occur

Soil unit	Parent material	Family	Association
Gleyic Cambisol	Aluvium derived from basic and ultrabasic rocks	Sinsulod	Karamuak
	Alluvium	Luba	Kinabatangan Tuaran Labau
Calcic Cambisol	Limestone	Madai	Gomantong
Humic Cambisol	Acid igneous rocks	Mantaki	Kinabalu
Chromic Cambisol	Alluvium	Mankawagu	Labau Brantian Sinarun
	Ultrabasic igneous rocks	Silad	Bidu Bidu Malubok
	Basic and intermediate igneous rocks	Kawa	Mentapok Malubok Tiger
	Acid igneous rocks	Sadok	Kinabalu
	Chert	Juak	Kretam Banggi Gumpal
	Sandstone and mudstone	Luasong	Lokan Crocker
Dystric Cambisol	Alluvium	Kelawat	Kinabatangan Tuaran Labau Binkor Sook
	Ultrabasic igneous rocks	Meliau	Bidu Bidu Tawai
	Basic igneous rocks	Nerelud	Tapang
	Tuffaceous rocks	Tenggara	Gumpal
	Chert	Durikong	Kennedy Bay
	Sandstone and mudstone	Laab	Lokan Crocker Dalit Mawing Gumpal
	Sandstone	Antulai	Maliau
Eutric Cambisol	Alluvium	Bulanat	Tuaran Karamuak Labau Binkor
	Ultrabasic igneous rocks	Binuang	Bidu Bidu Malubok Gumpal Bang
	Basic and intermediate igneous rocks	Bombalai	Gumpal Bang Mentapok Tiger Tinagat Wullersdorf Malubok
	Acid igneous rocks	Quarry	Wullersdorf
	Tuffaceous rocks	Hatton	Gumpal Tinagat

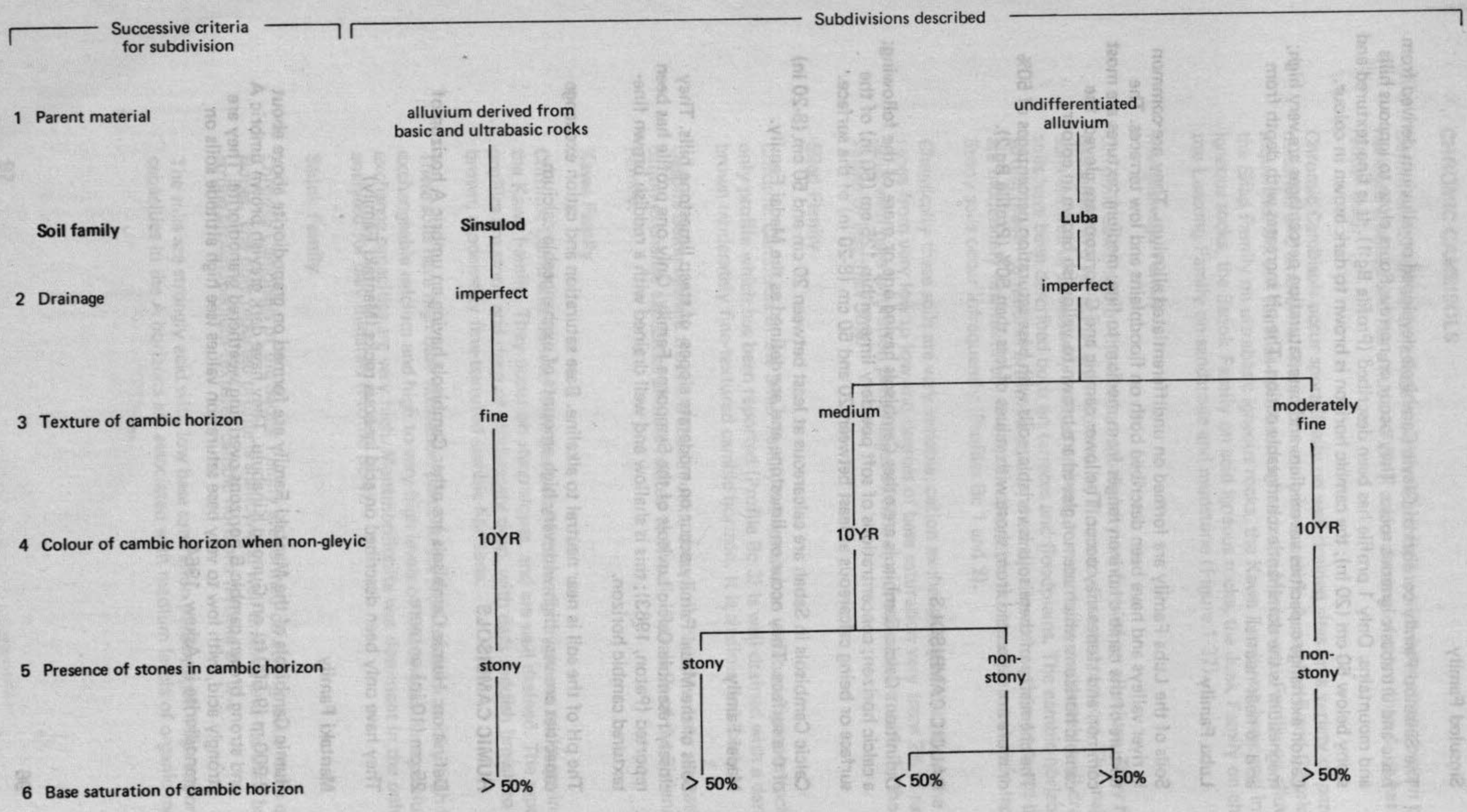


FIGURE 1-26 Gleyic Cambisols: criteria for subdivision and subdivisions described

Sinsulod Family

The Sinsulod Family consists of Gleyic Cambisols developed on alluvium derived from basic and ultrabasic igneous rocks. They occur on narrow floors close to igneous hills and mountains. Only 1 profile has been described (Profile Bg 1). It is fine-textured and stony below 50 cm (20 in); the cambic horizon is brown to dark brown in colour.

Cation exchange capacities are medium and base saturation percentages are very high; magnesium is the dominant exchangeable cation. The pH increases with depth from acid to near neutral.

Luba Family

Soils of the Luba Family are formed on undifferentiated alluvium. They are common in river valleys and have been described both on floodplains and low terraces. The texture of the cambic horizon ranges from medium to fine; medium textures are most common and stones may occur. The lower cambic and C horizons are gleyed; the cambic horizons which are not gleyed are brown to yellowish brown in colour.

The chemistry of these soils is variable; soils with base saturation percentages of 50% or more are separated from those with values of less than 50% (Profile Bg 2).

CALCIC CAMBISOLS

Definition: Calcic Cambisols are other Cambisols having one or more of the following: a calcic horizon; concentrations of soft powdery lime within 125 cm (50 in) of the surface or being calcareous at least between 20 and 50 cm (8-20 in) of the surface.

Calcic Cambisols in Sabah are calcareous at least between 20 cm and 50 cm (8-20 in) of the surface. They occur on limestone and are defined as the Madai Family.

Madai Family

Soils of the Madai Family occur on moderate slopes of steep limestone hills. They closely resemble Calcic Luvisols of the Semporna Family. Only one profile has been reported (Paton, 1963); this is shallow and well drained with a reddish brown fine-textured cambic horizon.

The pH of the soil is near neutral to alkaline. Base saturation and cation exchange capacities are very high with very high amounts of exchangeable calcium.

HUMIC CAMBISOLS

Definition: Humic Cambisols are other Cambisols having an umbric A horizon of 25 cm (10 in) or more.

They have only been described on acid igneous rocks (Mantaki Family)

Mantaki Family

Humic Cambisols of the Mantaki Family are formed on granodiorite above about 2 900 m (9 500 ft) on Gunong Kinabulu. They have dark greyish brown umbric A and strong brown cambic B horizons overlying weathered granodiorite. They are strongly acid, with low to very base saturation values (see high altitude soils on granodiorite in Askew, 1964).

CHROMIC CAMBISOLS

Definition: Chromic Cambisols are other Cambisols which have strong brown to red B horizons (rubbed soil has a hue of 7.5YR and a chroma of more than 4, or has a redder hue).

Chromic Cambisols occur sporadically on well drained sites on a variety of parent materials and landforms. They commonly have ochric A, cambic B and C horizon sequences. Six soil families have been defined: the Mankawagu Family on alluvium, the Silad Family on ultrabasic igneous rocks, the Kawa Family on basic and intermediate igneous rocks, the Sadok Family on acid igneous rocks, the Juak Family on chert and the Luasong Family on sandstone and mudstone (Figure 1-27).

Mangkawagu Family

Chromic Cambisols of the Mankawagu Family are formed on alluvium. They have been described on a variety of sites from valley floors to dissected terraces. The majority of soils are well or excessively drained and occur on terraces; moderately well drained soils have been described both on terraces and floodplains. The cambic horizons are strong brown to reddish brown in colour; the majority are medium-textured but several are moderately fine-textured; fine-textured cambic horizons have not been reported. Stony soils occur infrequently (Profiles Bc 1 and 2).

Chemically these soils are very variable; cation exchange capacities below the A horizon range from very low to low and degrees of base saturation vary from 2% to saturation. Soils with base saturation percentages of 50% or more are separated from those with values of less than 50%.

Silad Family

Chromic Cambisols of the Silad Family are formed on ultrabasic igneous rocks. The only profile which has been reported (Profile Bc 3) is well drained with a dark reddish brown moderately fine-textured cambic horizon. It is shallow and stony.

Despite being derived from ultrabasic rocks, these soils have low base saturations and cation exchange capacities and are related to Rhodic Ferralsols of the Pinianakan Family.

Kawa Family

Chromic Cambisols derived from basic and intermediate igneous rocks are included in the Kawa Family. They occur on steep slopes, and are well drained. The reported profiles are stony and deep or moderately deep, with dark reddish brown to reddish brown, moderately fine-textured cambic horizons.

These soils have high base saturation percentages with medium to very high levels of exchangeable calcium and high to very high levels of exchangeable magnesium. Cation exchange capacities are very high. Montmorillonite was dominant in the only profile analysed for clay minerals (Profile Bc 4).

Sadok Family

Chromic Cambisols of the Sadok Family are formed on acid igneous rocks on steep slopes. The only reported profile is shallow and well drained and has dark brown to strong brown medium-textured cambic horizons (Profile Bc 5).

The soils are strongly acid with low base saturation percentages. High cation exchange capacities in the A horizons are associated with medium levels of organic matter.

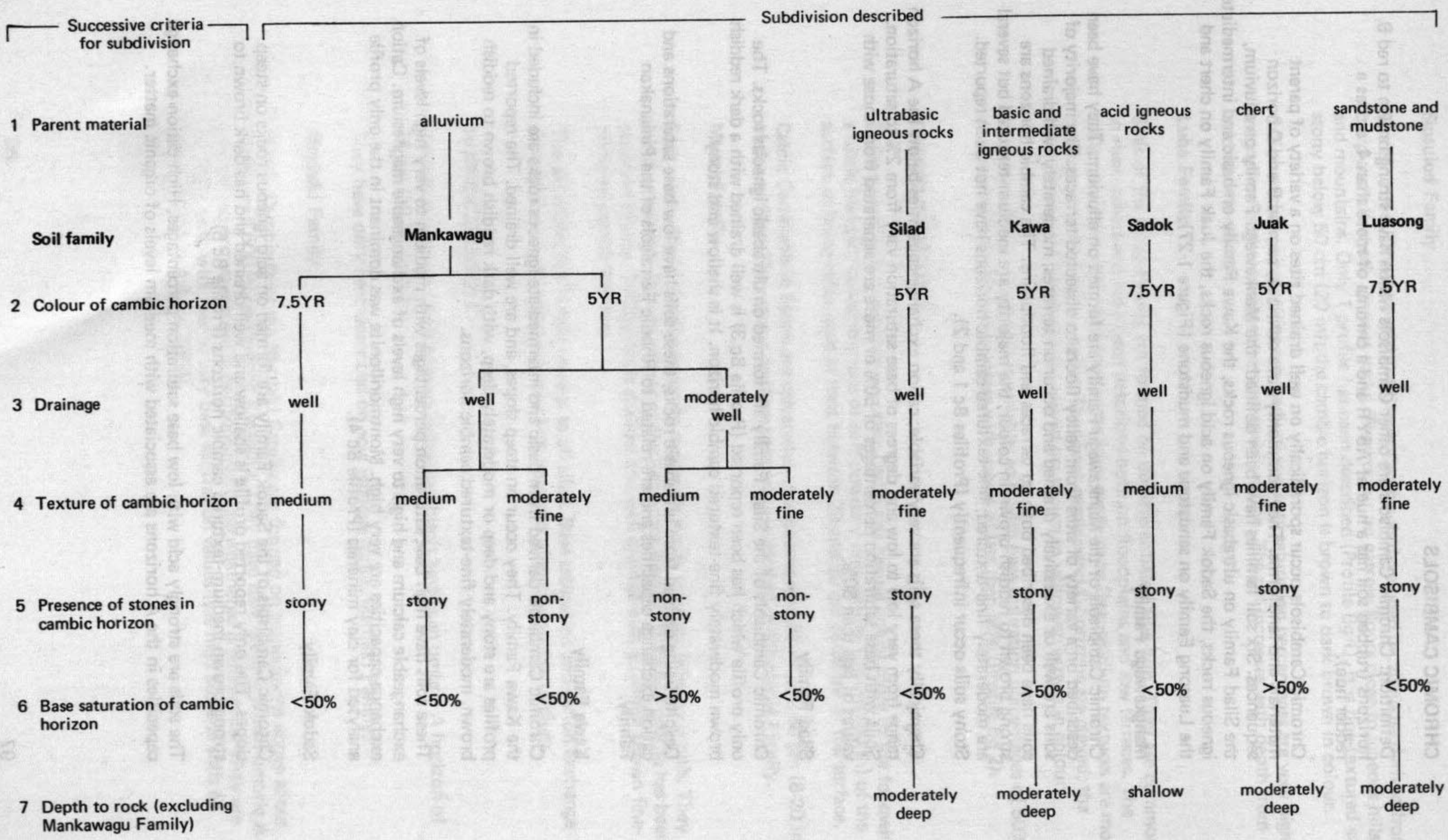


FIGURE 1-27 Chromic Cambisols: criteria for subdivision and subdivisions described

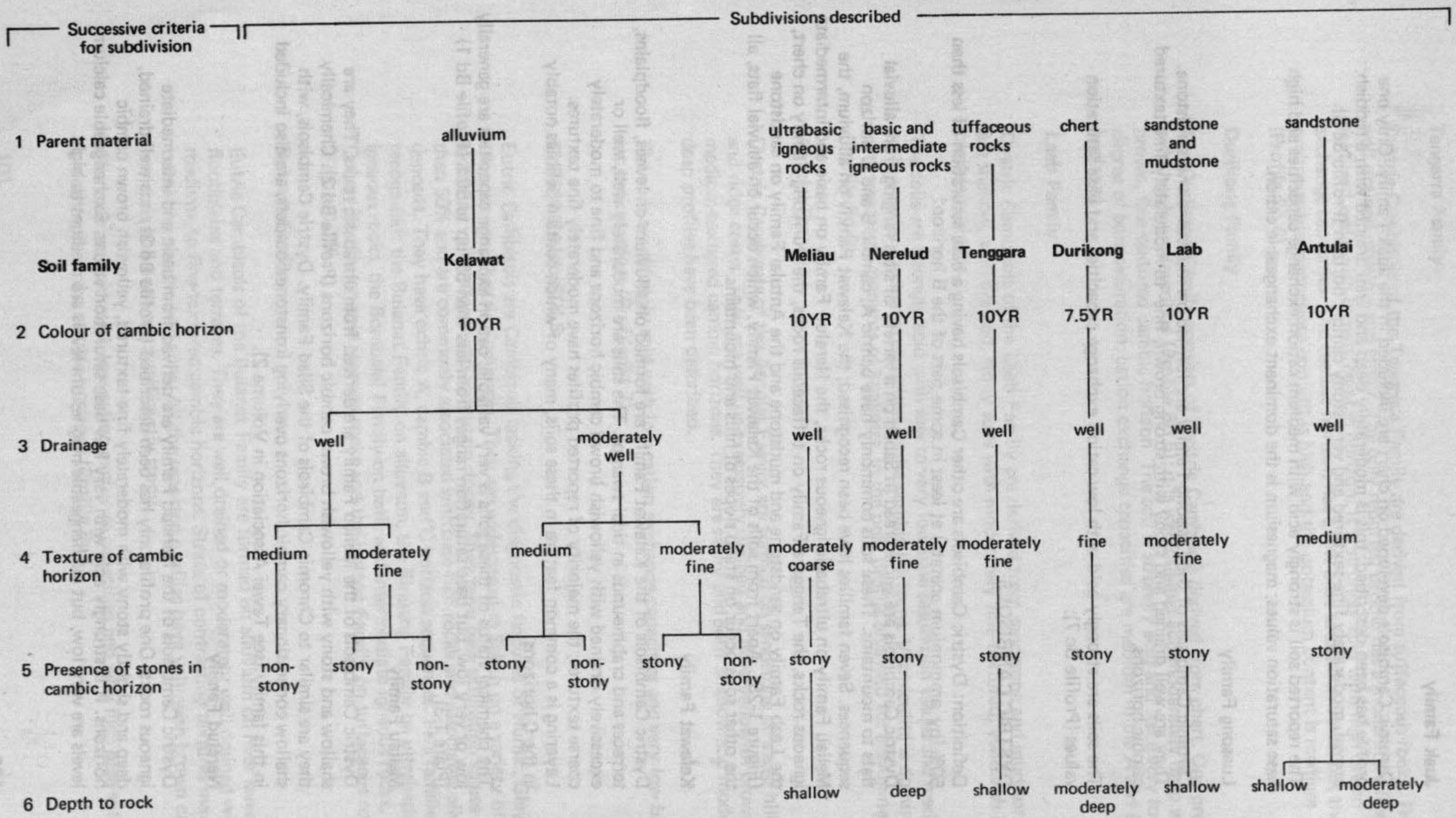


FIGURE 1-28 Dystric Cambisols: criteria for subdivision and subdivisions described

Juak Family

Chromic Cambisols developed on chert are included in the Juak Family. Only one profile has been described; this is moderately deep and well drained with a reddish brown, moderately fine-textured and very stony cambic horizon (Profile Bc 6).

The reported soil is strongly acid with medium cation exchange capacities and high base saturation values; magnesium is the dominant exchangeable cation.

Luasong Family

Chromic Cambisols of the Luasong Family are formed on mudstone and sandstone. They are well drained and stony with strong brown, fine- to moderately fine-textured cambic horizons.

The soils are strongly acid with low cation exchange capacities and base saturation values (Profile Bc 7).

DYSTRIC CAMBISOLS

Definition: Dystric Cambisols are other Cambisols having a base saturation of less than 50% (by ammonium acetate) at least in some part of the B horizon.

Dystric Cambisols are widespread in Sabah on a variety of sites ranging from alluvial flats to mountains. These soils commonly have ochric A, cambic B and C horizon sequences. Seven families have been recognised; the Kelawat Family on alluvium, the Meliau Family on ultrabasic igneous rocks, the Nerelud Family on basic and intermediate igneous rocks, the Tenggara Family on tuffaceous rocks, the Durikong Family on chert, the Laab Family on sandstone and mudstone and the Antulai Family on sandstone (Figure 1-28). Apart from soils of the Kelawat Family, which occur on alluvial flats, all the other soils occur on steep slopes of hills and mountains.

Kelawat Family

Dystric Cambisols of the Kelawat Family are formed on alluvium on levees, floodplains, terraces and crabmounds in tidal swamps. The soils are moderately well, well or excessively drained with yellowish brown cambic horizons and fine to moderately coarse textures; the majority of reported profiles have moderately fine textures. Layering is a common feature in these soils, many of which contain pebbles notably in the C horizons.

The chemical status of these soils is very variable; cation exchange capacities are generally low or very low, but base saturation ranges from less than 5% up to 50% (Profile Bd 1) (Plate 1-3).

Meliau Family

Dystric Cambisols of the Meliau Family are derived from ultrabasic rocks. They are shallow and stony with yellowish brown cambic horizons (Profile Bd 2). Chemically they are similar to Chromic Cambisols of the Silad Family. Dystric Cambisols, with shallow concretionary cambic horizons overlying ironstone boulders, are also included in this family (see Tawai Association in Volume 2).

Nerelud Family

Dystric Cambisols of the Nerelud Family are derived from basic and intermediate igneous rocks. One profile only has been described (Profile Bd 3); it is well drained, deep and slightly stony with moderately fine-textured, yellowish brown cambic horizons. It is strongly acid with very low base saturation values. Exchangeable calcium levels are very low, but exchangeable magnesium levels are medium to high.

Tengarra Family

Dystric Cambisols of the Tenggara Family are derived from tuffaceous rocks. They are well drained, shallow and stony. The only reported profile has a moderately fine-textured, yellowish brown, cambic horizon. It is strongly acid with high cation exchange capacities. The cambic horizon has a low base saturation value, but the exchangeable magnesium content is high and the potassium content is medium (Profile Bd 4).

Durikong Family

The Durikong Family consists of Dystric Cambisols derived from chert. One profile only has been described (Profile Bd 5); it is well drained and moderately deep with a brown, fine-textured cambic horizon. The soil is strongly acid and has a very low degree of base saturation; cation exchange capacities are medium in the A and B horizons.

Laab Family

Dystric Cambisols of the Laab Family are derived from sandstone and mudstone. They are shallow, well drained, stony soils with moderately fine-textured, yellowish brown cambic horizons.

The soils are strongly acid with low to very low base saturation values and medium to low cation exchange capacities in the cambic horizons. Vermiculite is dominant, with moderate amounts of kaolinite, in the only profile analysed for clay minerals (Profile Bd 6).

Antulai Family

Dystric Cambisols of the Antulai Family are formed on sandstone on steep hillsides and ridge crests. They are well or excessively drained and have yellowish brown, medium-textured cambic horizons. They are stony and both shallow and moderately deep profiles have been described.

The soils are strongly acid with low cation exchange capacities and very low base saturation values (Profile Bd 7).

EUTRIC CAMBISOLS

Eutric Cambisols are Cambisols lacking the diagnostic features of Humic, Gleyic, Calcic, Chromic and Dystric Cambisols. They are widespread in Sabah on a variety of sites, including valley floors and mountain slopes. They have base saturation values of more than 50% and are commonly associated with base-rich rocks and associated alluvial deposits. They have ochric A, cambic B and C horizon sequences. Five families are recognised: the Bulanat Family on alluvium, the Binuang Family on ultrabasic igneous rocks, the Bombalai Family on basic and intermediate igneous rocks, the Quarry Family on acid igneous rocks and the Hatton Family on tuffaceous rocks (Figure 1-29).

Bulanat Family

Eutric Cambisols of the Bulanat Family are formed on alluvium on river levees, floodplains and terraces. They are well drained or moderately well drained with medium- to fine-textured cambic horizons. Strata of contrasting textures may occur below the cambic horizons. All the reported profiles have yellowish brown cambic horizons and none are significantly stony.

The soils are acid, with low cation exchange capacities and very high base saturation percentages in the cambic horizons (Profile Be 1).

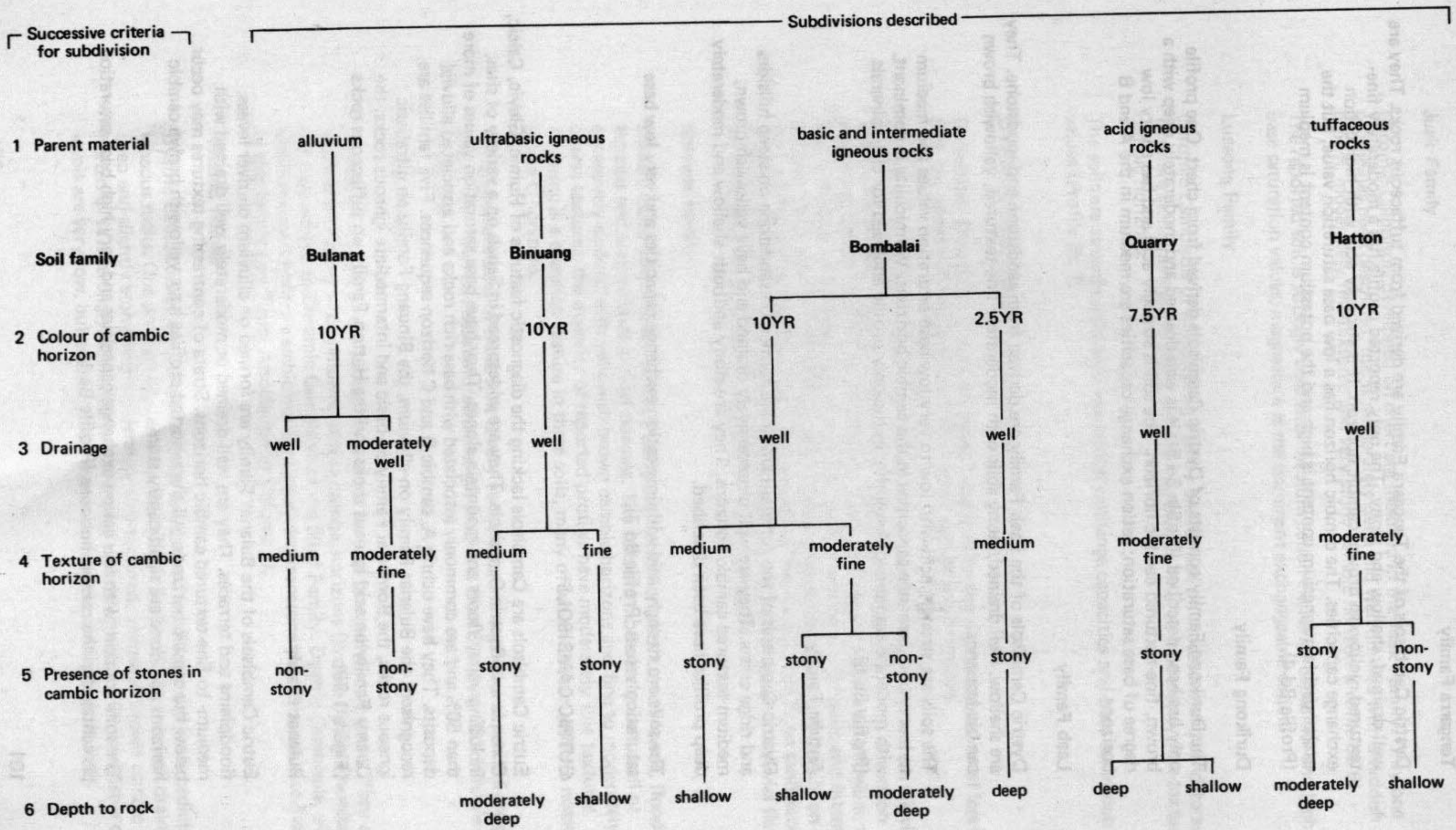


FIGURE 1-29 Eutric Cambisols: criteria for subdivision and subdivisions described

Binuang Family

Eutric Cambisols of the Binuang Family are derived from ultrabasic rocks. They occur on steep hillsides and ridge crests and are well drained, with greyish brown medium- to fine-textured cambic horizons. They are stony and are either shallow or moderately deep.

The soils have acid to near neutral reactions. Base saturation percentages are very high with magnesium dominating the exchange complex. Cation exchange capacities are high to very high in soils with fine-textured cambic horizons; they are low in those with medium textures (Profile Be 2).

Bombalai Family

The Bombalai Family consists of Eutric Cambisols derived from basic and intermediate igneous rocks. The soils occur on steep slopes or ridge tops and are well drained with medium- to fine-textured cambic horizons; moderately fine-textured soils are most common. Colours of the cambic horizons vary from olive brown (2.5YR hues), through yellowish brown (10YR hues) to brown (7.5YR hues). The soils range from being shallow and stony to moderately deep and stone-free.

The soils are generally acid with cation exchange capacities ranging from medium to very high; base saturation percentages are high to very high, often with high levels of exchangeable calcium and magnesium (see the Bombalai sub-family in Paton, 1963).

Quarry Family

Eutric Cambisols of the Quarry Family are formed on acid igneous rocks. They have only been described on dacitic lavas and ashes (Paton, 1963). They are well drained, shallow to deep and stony with moderately fine-textured, brown cambic horizons.

The soils are acid with medium to high cation exchange capacities and high base saturation values; exchangeable calcium levels are medium to low and magnesium levels are medium to high.

Hatton Family

The Hatton Family consists of Eutric Cambisols derived from tuffaceous rocks. They are well drained, with moderately fine-textured, yellowish brown cambic horizons. They are shallow to moderately deep and are often stony.

The soils are acid with high cation exchange capacities and base saturation values; the exchange complex is dominated by calcium or magnesium (Profile Be 3).

Arenosols

GENERAL DESCRIPTION

Definition: Arenosols are soils of coarse texture consisting of albic material or showing characteristics of argillic, cambic or oxic B horizons which, however, do not qualify as diagnostic horizons, too coarse to meet the textural requirements.

The Arenosols described in Sabah either form on albic material (Albic Arenosols) or show characteristics of cambic horizons (Cambic Arenosols). They are separated into families according to parent material (Table 1-11) and further subdivided using texture and colour of the B horizon, drainage, presence of a compact E horizon, stoniness and depth as criteria (Figure 1-30).

TABLE 1-11 Arenosols: soil families and the associations in which they commonly occur

Soil unit	Parent material	Family	Association
Albic Arenosol	Alluvium	Serai	Tanjong Aru Kepayan
Cambic Arenosol	Calcareous alluvium	Pisau	Usukan
	Alluvium	Kabili	Tuaran Tanjong Aru
	Sandstone	Pangarangan	Dalit Lokan Crocker Maliau

ALBIC ARENOSOLS

Definition: Albic Arenosols are Arenosols consisting of albic material.

Serai Family

The Serai Family is the only family of Albic Arenosols. It comprises soils formed on old beaches and terraces of coarse-textured alluvium. The alluvium is composed largely of quartz sand with more than 95% silica. Profiles have O, A, E or A,E horizon sequences and can be subdivided on the presence or absence of massive compact albic E horizons; where present, these compact horizons cause perched water tables and the soils are sometimes saturated with water. During dry periods, however, the soils appear to be excessively drained. Soils lacking compact albic horizons are also excessively drained. Spodic horizons occur in some soils below 125 cm (50 in) and are clearly related to Podzols on alluvium.

There are usually small accumulations of plant nutrients in the surface horizons but amounts in the albic horizons are negligible. Cation exchange capacities are often below 1 meq% in the Albic horizons and for this reason the apparently high base saturation figures, which have been recorded, must be discounted (Profiles Qa 1 and 2).

CAMBIC ARENOSOLS

Arenosols lacking the characteristics of the other Arenosols are termed Cambic Arenosols. They are soils of coarse texture, which have horizons showing cambic characteristics. They have been described on calcareous alluvium (Pisau Family), alluvium (Kabili Family) and sandstone (Pangarangan Family).

Pisau Family

The Pisau Family consists of Cambic Arensols formed on calcareous alluvium. The alluvium is derived largely from coral and is coarse-textured. The soils have A, B and C horizon sequences and are well to excessively drained. The B horizons which have been described, have strong brown colours.

Soil pH values are near neutral to alkaline and exchangeable calcium values are very high. Sodium values are high but potassium and magnesium are low or very low. Cation exchange capacities are medium in the A horizons but decrease to very low values in the C horizons (Profile Qc 1).

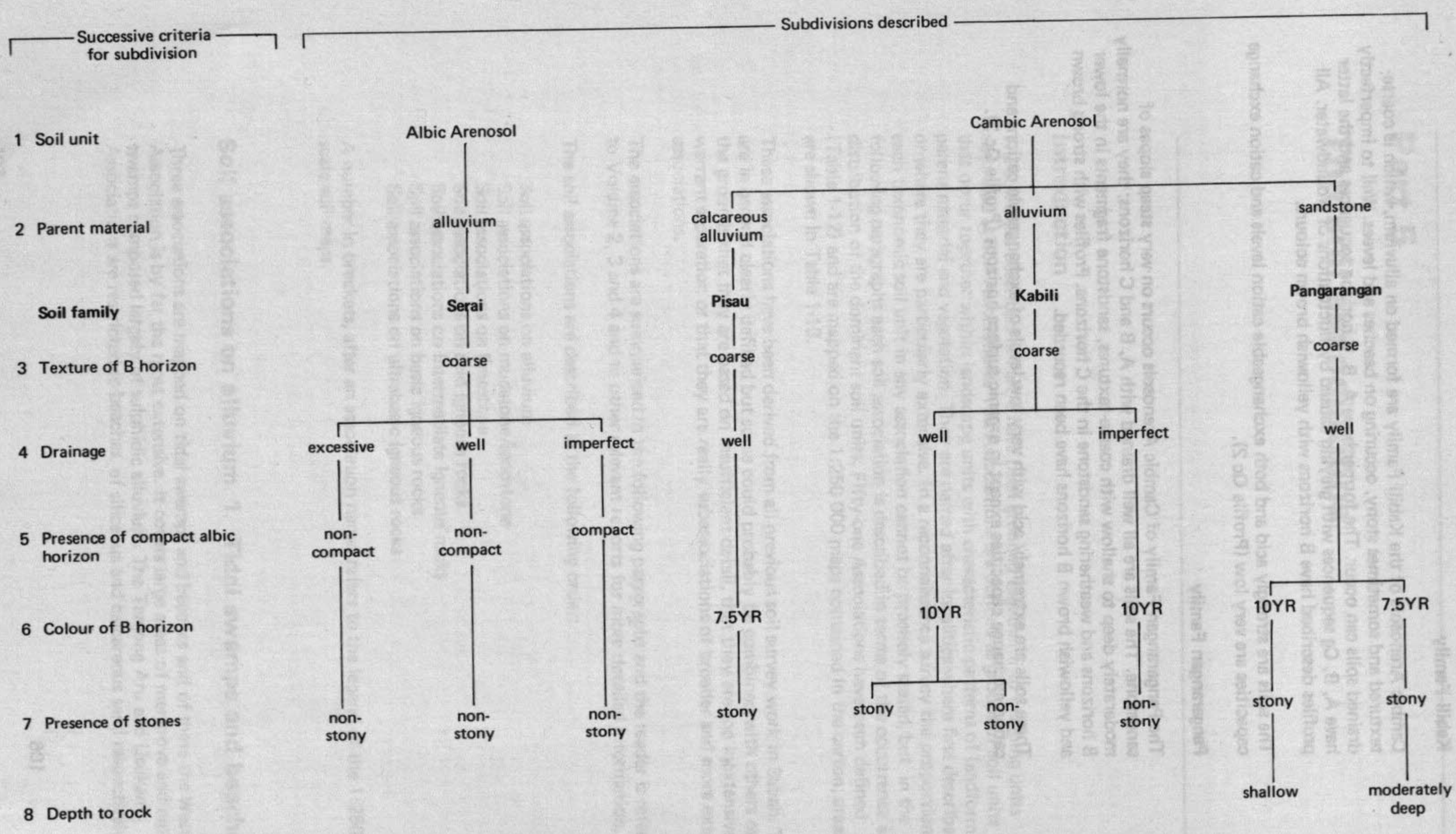


FIGURE 1-30 Arenosols: criteria for subdivision and subdivisions described

Kabili Family

Cambic Arenosols of the Kabili Family are formed on alluvium, which is coarse-textured and sometimes stony, occuring on beaches and levees. Well to imperfectly drained soils can occur. The former have A, B, C horizon sequences and the latter have A, B, Cg sequences with gleying caused by fluctuations of groundwater. All profiles described have B horizons with yellowish brown colours.

The soils are strongly acid and both exchangeable cation levels and cation exchange capacities are very low (Profile Qc 2).

Pangarangan Family

The Pangarangan Family of Cambic Arenosols occurs on very steep slopes of sandstone. The soils are all well drained with A, B and C horizons; they are normally moderately deep to shallow with coarse-textures, sandstone fragments in the lower B horizons and weathering sandstone in the C horizons. Profiles with strong brown and yellowish brown B horizons have been recorded.

These soils are extremely acid with very low levels of exchangeable cations and cation exchange capacities except in organic surface horizons (Profile Qc 3).

Part 5

The soil associations

Introduction

The soil units described in Part 4 have been grouped together into mapping units described as Soil Associations. The Associations are defined as groups of soil units that occur together within landscape units with characteristic patterns of landform, parent material and vegetation. They are named after localities where first described, or where they are particularly extensive. In a reconnaissance survey the proportions of each taxonomic soil unit in any association cannot be precisely stated, but in the following paragraphs each soil association is described in terms of the occurrence and distribution of the dominant soil units. Fifty-one Associations have been defined (Table 1-12) and are mapped on the 1:250 000 maps contained in the carton; areas are shown in Table 1-13.

These associations have been derived from all previous soil survey work in Sabah. They are in general clearly defined but some could probably be combined with others on the grounds that they are based on insufficient detail, that they are too inextensive to warrant separation or that they are really subassociations of broader and more extensive associations.

The associations are summarised in the following paragraphs and the reader is referred to Volume 2, 3 and 4 and to other relevant reports for more detailed information.

The soil associations are described in the following order:

- Soil associations on alluvium
- Soil associations on mudstone/sandstone
- Soil associations on limestone
- Soil associations on acid igneous rocks
- Soil associations on intermediate igneous rocks
- Soil associations on basic igneous rocks
- Soil associations on ultrabasic igneous rocks

A number in brackets, after an association name, refers to the legend of the 1:250 000 scale soil maps.

Soil associations on alluvium 1. Tidal swamps and beaches

Three associations are mapped on tidal swamps and beaches and of these the Weston Association is by far the most extensive. It covers large areas of mangrove and nipah swamps composed largely of sulphidic alluvium. The Tanjong Aru and Usukan Associations are restricted to beaches of siliceous and calcareous sand respectively.

TABLE 1-12 The soil associations as shown on the 1:250 000 map The soils of Sabah

Key	Association	Landform	Parent material	Main soil units
1	Weston	Tidal swamps	Sulphidic alluvium, sulphidic peat and alluvium	Thionic Fluvisol; Dystric Histosol; Thionic Gleysol
2	Usukan	Beaches	Calcareous alluvium	Calcaric Regosol; Humic Gleysol
3	Tanjong Aru	Beaches	Alluvium	Dystric and Eutric Regosols; Humic, Dystric and Eutric Gleysols; Gleyic Podzol
4	Tuaran	Meander belts	Alluvium	Eutric Fluvisol; Gleyic Dystric and Eutric Cambisols; Humic, Dystric and Eutric Gleysols
5	Kinabatangan	Floodplains	Alluvium	Gleyic Acrisol; Gleyic Luvisol; Humic, Dystric and Eutric Gleysols
6	Sapi	Swamps	Alluvium and peat	Humic, Dystric and Eutric Gleysols; Dystric Histosol
7	Klias	Swamps	Peat and alluvium	Dystric Histosol; Humic Gleysol
8	Binalik	Valley floors and terraces	Alluvium derived from ultrabasic rocks	Orthic Ferralsol; Gleyic, Ferric and Orthic Luvisols; Ferric and Orthic Acrisols
9	Keramuak	Valley floors and terraces	Alluvium and alluvium derived from basic and ultrabasic rocks	Gleyic, Chromic and Orthic Luvisols; Gleyic and Eutric Cambisols; Eutric Fluvisol
10	Labau	Valley floors and terraces	Alluvium	Gleyic and Dystric Cambisols; Dystric and Eutric Fluvisols; Gleyic and Orthic Acrisols
11	Binkor	Terraces	Alluvium	Dystric and Eutric Gleysols; Gleyic Luvisol
12	Brantian	Terraces	Alluvium	Orthic, Ferric and Gleyic Acrisols; Gleyic Podzol
13	Kepayan	Terraces	Alluvium	Gleyic Podzol; Gleyic Acrisol
14	Sook	Terraces	Alluvium	Gleyic and Orthic Acrisols; Gleyic Podzol; Dystric Gleysol
15	Sipitang	Swamps	Peat and alluvium	Dystric Histosol; Gleyic Podzol
16	Sinarun	Dissected terraces: slopes 15-25°	Alluvium, sandstone and mudstone	Orthic Acrisol; Dystric Gleysol; Dystric Cambisol

TABLE 1-12 (continued)

Key	Association	Landform	Parent material	Main soil units
17	Tungku	Terraces	Calcareous alluvium	Chromic and Gleyic Luvisols
18	Pinosuk	Plateau with gently undulating surface and dissected terraces with slopes up to 25°	Colluvium, sandstone and mudstone	Gleyic Podzol; Gleyic and Orthic Acrisols; Humic and Dystric Gleysols
19	Tawai	Plateau with gently undulating surface	Ironstone and alluvium derived from ultrabasic rocks	Dystric Histosol; Dystric Gleysol; Dystric Cambisol
20	Tapang	Low hills (slopes 0-15°), terraces and valley floors	Basic igneous rocks and alluvium	Xanthic Ferralsol; Orthic Acrisol; Orthic Luvisol; Eutric Gleysol
21	Semporna	Very low hills: slopes 0-5°	Limestone	Calcic and Chromic Luvisols; Rendzina
22	Lungmanis	Very low hills (slopes 0-15°) and valley floors	Mudstone and alluvium	Gleyic, Ferric and Orthic Acrisols; Gleyic Ferric, Chromic and Orthic Luvisols
23	Table	Dissected plateaus with flat to gently undulating surfaces	Basic igneous rocks	Zanthic and Orthic Ferralsols
24	Orchid Plateau	Plateau of low hills: slopes 15-20°	Basic and intermediate igneous rocks	Orthic Acrisol; Orthic and Chromic Luvisols
25	Silabukan	Low hills and minor valley floors: slopes 0-15°	Mudstone and alluvium	Gleyic, Ferric and Orthic Acrisols; Gleyic, Ferric, Chromic and Orthic Luvisols
26	Rumidi	Low hills and minor valley floors: slopes 0-15°	Mudstone, sandstone and miscellaneous rocks	Gleyic, Ferric and Orthic Acrisols; Gleyic, Ferric Chromic and Orthic Luvisols
27	Sipit	Low hills: slopes 0-15°	Mudstone, sandstone and miscellaneous rocks	Ferric and Orthic Acrisols; Orthic Luvisol
28	Apas	Moderate hills: slopes 15-25°	Intermediate and acid igneous rocks	Rhodic Ferralsol; Orthic Acrisol; Eutric Cambisol
29	Kalabakan	Moderate hills: slopes 0-20°	Mudstone and sandstone*	Ferric and Orthic Acrisols; Ferric, Chromic and Orthic Luvisols
30	Mawing	Moderate hills: slopes >25°	Mudstone and sandstone*	Orthic Acrisol; Dystric Cambisol
31	Dalit	Moderate hills and minor valley floors: slopes 0-20°	Sandstone, mudstone and alluvium	Orthic, Ferric and Gleyic Acrisols
32	Tengah Nipah	Moderate hills and minor valley floors: slopes 0-20°	Sandstone, mudstone and alluvium	Ferric, Orthic and Gleyic Acrisols
33	Kretam	Moderate hills: slopes 0-20°	Mudstone, sandstone and miscellaneous rocks	Ferric and Orthic Acrisols; Ferric, Chromic and Orthic Luvisols
34	Beruang	High hills: slopes 15-25°	Basic igneous rocks	Ferric Acrisols; Orthic Luvisol

* Corresponds in subsequent volumes with Mudstone and Minor Sandstone in Text Maps 2-4, 3-4 and 4-4;

TABLE 1-12 (continued)

Key	Association	Landform	Parent material	Main soil units
35	Dagat	Moderate hills: slopes 10-20°	Tuffaceous rocks, mudstone and sandstone	Chromic and Orthic Luvisols; Orthic Acrisol
36	Kennedy Bay	High hills: slopes >25°	Sandstone, mudstone and igneous rocks	Ferric Acrisol; Chromic and Orthic Luvisols; Dystric and Eutric Cambisols
37	Tiger	Very high hills: slopes >25°	Basic igneous rocks	Chromic and Eutric Cambisols
38	Gomantong	Very high hills: slopes >25°	Limestone	Calcic Luvisol; Rendzina
39	Lokan	Very high hills: slopes >25°	Sandstone and mudstone	Orthic Acrisol; Dystric Cambisol
40	Bang	Very high hills: slopes 15-25°	Mudstone, sandstone and miscellaneous rocks	Orthic Acrisol; Dystric Cambisol
41	Bidu Bidu	Mountains and hills	Ultrabasic igneous rocks	Rhodic and Orthic Ferralsols; Eutric Cambisol; Chromic and Orthic Luvisols; Lithosol
42	Mentapok	Mountains	Basic and intermediate igneous rocks	Chromic and Orthic Luvisols; Eutric Cambisol; Lithosol
43	Tinagat	Mountains	Basic and intermediate igneous rocks	Eutric Cambisol; Lithosol; Ferric Luvisol
44	Malubok	Mountains	Igneous rocks, sandstone, mudstone and chert	As for Associations 41, 42 and 47 with Chromic Cambisols and Lithosols on chert
45	Wullersdorf	Mountains	Intermediate and acid igneous rocks	Eutric Cambisol; Lithosol
46	Gumpal	Mountains and hills	Mudstone, sandstone and miscellaneous rocks	Orthic Acrisol; Orthic Luvisol; Dystric and Eutric Cambisols; Lithosol
47	Crocker	Mountains	Sandstone and mudstone	Orthic Acrisol; Chromic and Dystric Cambisols; Lithosol
48	Maliau	Mountain cuestas	Sandstone and mudstone	Orthic Acrisol; Dystric Cambisol; Gleyic Podzol; Humic Gleysol; Lithosol
49	Serudong	Dipslopes of mountain cuestas	Sandstone	Gleyic Podzol; Orthic Acrisol
50	Trusmadi	Mountains above 1 200 m (4 000 ft) a.s.l.	Sandstone and mudstone	Gleyic and Orthic Acrisols; Gleyic Podzol; Humic Gleysol; Dystric Histosol; Lithosol
51	Kinabalu	Mountains above 2 400 m (8 000 ft) a.s.l.	Acid igneous rocks	Humic Cambisol; Dystric Histosol; Lithosol

TABLE 1-13 Areas of soil associations in square kilometres and square miles (initial measurements in km^2 with approximate conversion to mi^2). Associations listed in descending order of area

Key	Association	Area km^2	Area mi^2
47	Crocker	17 782	6 870
48	Maliau	8 543	3 300
39	Lokan	8 436	3 254
1	Weston	4 171	1 610
33	Kretam	3 256	1 254
31	Dalit	3 144	1 212
46	Gumpal	2 885	1 120
12	Brantian	2 818	1 080
5	Kinabatangan	2 631	1 015
42	Mentapok	2 272	877
26	Rumidi	2 166	836
41	Bidu Bidu	1 821	703
7	Klias	1 212	468
22	Lungmanis	1 187	458
50	Trusmadi	1 098	424
4	Tuaran	999	386
40	Bang	899	347
44	Malubok	848	327
29	Kalabakan	816	315
6	Sani	794	306
16	Sinarun	710	274
45	Wullersdorf	592	228
25	Silabukan	574	222
3	Tanjong Aru	568	219
10	Labau	566	219
32	Tengah Nipah	524	202
36	Kennedy Bay	457	176
14	Sook	424	164
43	Tinagat	339	131
27	Sipit	316	122
13	Kepayan	278	107
30	Mawing	254	98
28	Apas	249	96
35	Dagat	231	89
21	Semporna	217	84
49	Serudong	213	82
23	Table	201	78
8	Binalik	193	75
20	Tapang	193	75
11	Binkor	139	54
51	Kinabalu	127	49
9	Karamuak	93	36
17	Tungku	82	32
18	Pinosuk	75	29
34	Beruang	66	25
38	Gomantung	45	17
15	Sipitang	38	15
24	Orchid Plateau	37	14
2	Usukan	33	13
19	Tawai	15	6
37	Tiger	9	3
	TOTAL	75 636	29 550

WESTON ASSOCIATION (1) 4171 km^2 (1610 mi^2)

The Weston Association is extensive in bays and estuaries. On the west coast there are major developments in the Padas delta and around Marudu Bay; on the east coast the association is almost continuous from the Bengkoka Peninsula to the Dent Peninsula with major developments in Schomburgk Bay, Labuk Bay, Sandakan Harbour and in the deltas of the Kinabatangan and Segama; in the south-east it is particularly extensive in Cowie Harbour. The association is formed in tidal swamps with 3 distinctive landforms, namely tidal flats, 'crab' mounds and platforms formed of coalescent 'crab' mounds. Parent materials consist of mainly fine-textured sulphidic alluvium and peat. The natural vegetation comprises forests of mangroves and nipah palm (*Nypa fruticans*).

Thionic Fluvisols of the Weston and Kalibong Families are the dominant soils on the tidal flats and in areas of 'crab' mounds and Thionic-humic, Thionic-dystric and Thionic-eutric Gleysols of the Bergosong, Metah and Libur Families occur on the platforms of coalescent 'crab' mounds. Calcaric Fluvisols of the Nunuyan Family form on calcareous alluvium in swamps close to coral beaches and Dystric Histosols of the Arang Family are locally dominant on sulphidic peat, for example in Sandakan Harbour.

The association is described in Volumes 2, 3 and 4 and it also includes the following units mapped in other regional surveys:

1. The Peras, Tambalang, Weston and Mengkabong Series in the Tuaran District (Wilson, 1969b)
2. The Abai and Rampayan Series in the Kota Belud District (Wilson, 1969a)
3. The Weston and Padas Series in the Kudat District (Belsham, 1969)
4. The Weston and Peras Series in the Darvel Bay area (Thomas, 1967a)

USUKAN ASSOCIATION (2) 33 km^2 (13 mi^2)

The Usukan Association occurs on the coast and islands; there are notable developments on Pulau Labuan, at Kuala Penyu, on Pulau Mengalum, Pulau Mantanani Besar, on the Sandakan Peninsula and on adjacent islands from Libaran in the north to Berhala in the south and on the east coast of the Dent Peninsula. The association is formed on beaches of calcareous alluvium; many beaches are formed of coarse-textured coral debris and coralline sand.

Calcaric Regosols of the Usukan Family are dominant on the beaches in association with Calcaric Fluvisols and Cambic Arenosols of the Nunuyan and Pisau Families. Humic Gleysols and Eutric Histosols of the Berhala and Mengalum Familes occur in poorly drained swales.

The association is described in Volumes 2 and 4 and it also includes the Mantanani Pantai and Mantanani Darat Series described in the Kota Belud District (Wilson, 1969a).

TANJONG ARU ASSOCIATION (3) 568 km^2 (219 mi^2)

The Tanjong Aru Association occurs intermittently around the coast with major developments between Kuala Penyu and Papar, at Tanjong Aru, Tuaran, Kota Belud, north and south of Trusan on the Sugut estuary and between Sandakan and the Segama estuary. The association occurs on coastal beaches, beach strands and on old beaches, which most commonly are inland from the present-day coast, but may be at the coast, where there is active erosion; The beaches are often in series of parallel ridges with intervening swales. The soils are formed on alluvium mainly in the form of siliceous sand, but between Kuala Abai and Pandasan, in the Kota Belud District, the sands contain relatively high contents of ferromagnesian minerals.

Dystric and Eutric Regosols of the Tamanong and Tanjong Lita Families occur on recent beach ridges, with Cambic Arenosols of the Kabili Family on slightly older beach flats just inland. Gleyic Podzols of the Baiayo Family are the dominant soils on old beaches, but Humic Podzols have been described near Kuala Penyu. Humic, Dystric and Eutric Gleysols of the Guan, Koyah and Bangawat Families occur in the poorly drained Swales. Albic Arenosols of the Serai Family and Orthic Podzols of the Silimpopon Family have been described on old beaches on the south of the Dent Peninsula and on Pulau Balambangan.

The association is described in Volumes 2 and 4 and it also includes the following units:

1. The Tamanong, Santang, Dalit, Tanjong Lita, Trayong, Gayang, Laya and Rhododendron Series in the Tuaran District (Wilson, 1969b).

2. The Pantai, Dakat Pantai, Tamau, Nananum, Kulambai, Pongor, Tanjong Lita, Tambok, Tamanong, Dalit and Benoni Series in the Kota Belud District (Wilson, 1969a).

3. The Benoni and Laya Series in the Kudat District (Belsham, 1969).

4. The Laya Series in the Sugut estuary (McCredie, 1970a).

5. The Tanjong Lita Series in the Dent Peninsula (Thomas 1967a).

6. The Tanjong Family in the Semporna Peninsula (Paton 1963).

Soil associations on alluvium 2. Floodplains

The soils of the river floodplains have been grouped into 4 associations, which together form a sequence extending from the meander belts across the true floodplains to backswamps. The Tuaran Association is mapped on the meander belts and with distance from the rivers this passes into the Kinabatangan Association on the true floodplains; the Sapi Association occurs in swamps and the Klias Association in peat swamps.

TUARAN ASSOCIATION (4) 999 km^2 (386 mi^2)

The Tuaran Association occurs on the meander belts of the main rivers throughout the State with major developments along the Sugut, Labuk, Kinabatangan and Segama, which drain to the east coast; on the west coast the major developments are along the Padas, Papar, Tuaran and Wariu and along the rivers draining into Marudu Bay. The association is also extensive on the meander belts of the Pagalan and Padas in the Tenom Plain. The meander belts include levees, meander scrolls and cut-off lakes. The soils are formed on alluvium of variable texture; on the levees, for example, it is normally coarse-textured and on infilled cut-offs it is fine-textured.

Dystric and Eutric Fluvisols of the Tenghilan and Pegalan Families are the dominant soils on the actively forming levees. Gleyic, Dystric and Eutric Cambisols of the Luba, Kelawat and Bulanat Families and Cambic Arenosols of the Kabili Family occur on older levees and flats away from the rivers. The cut-offs are generally very poorly drained and contain Humic, Dystric and Eutric Gleysols of the Guan, Koyah and Bangawat Families.

The association is described in Volumes 2 and 4 and it also includes the following units:

1. The Darau, Tagas, Gum Gum and Bangawat Series in the Tuaran District (Wilson, 1969b).

2. The Gusi Series in the Kota Belud District (Wilson, 1969a).

3. The Darau and Buran Series in the Kudat District (Belsham, 1969).

4. The Gum Gum and Darau Series along the Sungai Sugut (McCredie, 1970a) and in the Tungku and Sabahat valleys (Thomas, 1967a).

5. The Sumilad, Maralabu and Kiabau Series in the Labuk valley (Hooper and Ives, 1964).

KINABATANGAN ASSOCIATION (5) 2631 km^2 (1015 mi^2)

The Kinabatangan Association occurs on the floodplains of rivers throughout the State, with major developments along the Sugut, Labuk, Kinabatangan, Segama, Merbau, Silabukan and Kalumpang on the east coast and along the Mengalong, Papar, Putatan, Tampasuk and Bandau on the west coast. Periodic floods are particularly severe on the major east coast rivers.

The soils are largely formed on fine-textured alluvium and poorly drained Gleyic Acrisols and Gleyic Luvisols of the Inanam and Buran Families are dominant. Very poorly drained Humic, Dystric and Eutric Gleysols of the Guan, Koyah and Bangawat Families occur in the wettest sites.

The association is described in Volume 2, 3 and 4 and it also includes the following units.:

1. The Buran, Pinang and Bangawat Series in the Tuaran District (Wilson, 1969b).

2. The Rangarau, Inanam, Pandasan, Kelawat, Kinasaraban, Luba and Timbang series in the Kota Belud District (Wilson, 1969a).

3. The Inanam, Tagas and Bangawat Series in the Kudat District (Belsham, 1969).

4. The Pinang and Bangawat Series along the Paitan and Sugat rivers (McCredie 1970a) and in the Dent Peninsula (Thomas 1967a).

5. The Sapang and Balung Families in the Semporna Peninsula (Paton, 1963).

6. The Buloh, Pinang and Maunad Series in the Labuk valley (Hooper and Ives, 1964).

SAPI ASSOCIATION (6) 744 km^2 (306 mi^2)

The Sapi Association is extensive in swamps along the major rivers of the east coast, in the lower reaches and estuaries of the Sugut, Labuk, Klagan, Sapi, Kinabatangan and Segama; on the west coast it occurs in minor valleys notably between Menggatal and Telipok. The swamps are often under water. The soils are mainly formed on fine-textured alluvium.

Humic, Dystric and Eutric Gleysols of the Guan, Koyah and Bangawat Families are widespread; Dystric Histosols of the Klias Family occur on inextensive peat deposits.

The association is described in Volumes 2, 3 and 4 and also include the following units:

1. The Kawang Series in the Kota Belud District (Wilson, 1969a)

2. The Bangawat Series in the Kudat District (Belsham, 1969) and Sugut District (McCredie, 1970a)

3. The Bangawat and Kinau Series in the Dent Peninsula (Thomas, 1967a)

4. 'Freshwater swamps' in the Semporna Peninsula (Paton, 1963).

KLIAS ASSOCIATION (7) 1212 km^2 (468 mi^2)

The Klias Association occurs in peatswamps notably in the Klias Peninsula, in the Krah swamp near Kota Belud, in the Sugat and Labuk estuaries and in the lower reaches and estuaries of the Kinabatangan and Segama. The soils are formed on deposits of peat, which overlie alluvium; depths of up to 12 m (40 ft) of peat have been recorded.

Dystric Histosols of the Klias Family are dominant with Humic Gleysols of the Guan Family on shallow peat overlying alluvium; Dystric Histosols of the Arang Family occur sporadically.

The association is described in Volumes 2 and 3 and also includes the following units:

1. Organic soils in the Krah Swamp (Wilson, 1969a) (Thomas, 1963).
2. The Krah and Anam Series on Pulau Balambangan and west of Kudat (Belsham, 1969).
3. The Krah and Mansalak Series in the Sugut District (McCredie 1970a).
4. The Bayok Mucks and Klagan Peats in the Labuk estuary (Hooper and Ives, 1964)
5. The Mansalak Family in the Dent Peninsula (Thomas 1967a)

Soil associations on alluvium 3. Valley floors and associated terraces

Four soil associations have been mapped in the narrow valleys and upper reaches of many rivers. They all include a wide range of soils and are separated largely on the basis of the origin of the alluvial parent materials. The soils of the Binalik Association are formed on alluvium derived largely from ultrabasic rocks and the soils of the Karamuak Association are formed on alluvium derived largely from basic rocks. The Labau and Binkor Associations are both formed on alluvium derived from sandstone and mudstone and contain a similar range of soils; they could probably be merged.

BINALIK ASSOCIATION (8) 193 km^2(75 mi^2)

The Binalik Association occurs on alluvium mainly in the vicinity of the Maliau, Bidu Bida, Tawai and Silam mountain ranges; it also occurs on Pulau Banggi and on the eastern edge of Marudu Bay. The association is formed predominantly on alluvial fans, which are associated withstreams emerging from the mountains which are composed of ultrabasic igneous rocks; it is also formed on narrow floodplains and on terraces. The alluvium, which is largely derived from ultrabasic rocks, is fine or medium in texture and often contains stones or concretions.

The association includes Ferralsols, Acrisols and Luvisols. Orthic Ferralsols, of the Nobusu Family are dominant on alluvial fans with Ferric, Chromic and Orthic Luvisols, of the Pantagaluang, Mangkap and Numatoi Families, respectively, on low terraces and floodplains. Gleyic Luvisols of the Nangoh Family are restricted to poorly drained sites and Ferric and Orthic Acrisols, of the Lumisir and Katai Families, occur mainly on high terraces.

The association is described in Volume 2 and the following units are also included:

1. The Sabor Variants in the Pulau Banggi and Marudu Bay areas (Belsham, 1969)
2. The Nangoh, Katai and Telupid Series in the Meliau and Bidu Bidu areas (Hooper and Ives, 1964).
3. The Sabahat and Taliwas Series near Gunong Silam (Thomas, 1967a).

KARAMUAK ASSOCIATION (9) 93 km^2 (36 mi^2)

The Karamuak Association occurs on valley floors and terraces along the Sungai Karamuak, in the Mananam Plain, in the headwaters of the Bole and Segama and along the Sungai Kadamaian. Parent materials comprise fine- to coarse-textured, sometimes stony, alluvium, derived from mixed sources, but including basic igneous rocks.

The association includes Luvisols, Cambisols and Fluvisols. Orthic and Chromic Luvisols of the Numatoi, Darau and Sabor Families occur mainly on terraces and Eutric Cambisols of the Bulanat Family occur on narrow floodplains and levees. Gleyic Cambisols of the Sinsulod Family and Gleyic Luvisols of the Buran Family are restricted to poorly drained sites and Eutric Fluvisols of the Pegalan Family to levees and eyots.

The association is described in Volumes 2 and 3 and the following soils are also included:

1. The Limbasan, Melapi, Mananam, Enteleben, Liwotong-pau, Minau and Tongkabira Series in the Mananam Plain and Karamuak valley (Hooper and Ives, 1964)

2. A part of the Kadamaian valley in the Kota Belud District has also been included in the association. In this area Orthic and Ferric Acrisols of the Katai and Lumisir Families occur on low terraces and terrace remnants (see Panataran and Tamu Darat Series in Wilson, 1969a).

LABAU ASSOCIATION (10) 566 km^2 (219 mi^2)

The Labau Association occurs sporadically in the valleys of the upper reaches of many rivers. It was first described in the valley of the Sungai Labau in the headwaters of the Kinabatangan; other notable occurrences are in the Kuamut valley, the Sook, Keningau, Tenom, Tambunan, Ranau and Lohan Plains, the Labuk valley between Rumidi and Budu and above Tampias and the Umas Umas and Brantian valleys. The association occurs on narrow valley floors with eyots, levees, narrow floodplains and terraces. The soils are formed on alluvium, which is derived mainly from sedimentary rocks and which is often coarse-textured and stony.

The association is comprised of Fluvisols, Cambisols, Gleysols and Acrisols. Dystric and Eutric Fluvisols of the Tenghilan and Pegalan Families occur on eyots and levees; Gleyic, Chromic, Dystric and Eutric Cambisols of the Luba, Mankawagu, Kelawat and Bulanat Families occur on the narrow floodplains with Dystric and Eutric Gleysols of the Koyah and Bangawat Families in very poorly drained sites; Gleyic, Ferric and Orthic Acrisols of the Inanam, Lumisir and Paliu Families occur on the terraces.

The association is described in Volumes 2, 3 and 4 and also includes the following units:

1. The Mariu, Kelawat and Luba Series in the Kota Belud District (Wilson, 1969a)

2. The Gum Gum, Lungmanis and Sumilad Series in the Labuk valley (Hooper and Ives 1964).

BINKOR ASSOCIATION (11) 139 km^2 (54 mi^2)

The Binkor Association occurs mainly in the Tambunan, Keningau and Tenom Plains on river terraces with flat to gentle slopes and only minor dissection. Soil parent materials consist ofmedium- to coarse-textured alluvium, which is often stony particularly in the Tambunan Plain and in the Keningau Plain between Binkor and Bunsit.

The association contains a wide range of soils (see Volume 4), but Dystric and Eutric Gleysols of the Koyah and Bangawat Families predominate; Gleyic Luvisols of the Buran Family are also important notably in the Tenom Plain. Dystric and Eutric Fluvisols and Cambisols occur close to small streams.

Soil associations on alluvium 4. Terraces

Seven associations are mapped on terraces. Of these the Brantian, Sook, Sinarun, Kepayan and Sipitang Associations are closely related and there is considerable overlap of soil units. The Brantian Association is the most extensive and occurs on coastal terraces, valley terraces and on terraces in the inland plains. It consists mainly of well drained Orthic Acrisols on medium- and fine-textured old alluvium. In contrast the Sook Association consists largely of poorly drained Gleyic Acrisols on medium-and coarse-textured alluvium. Dissected terraces with well drained Orthic Acrisols on old alluvium and on sandstone and mudstone, exposed by the dissection, are included in the Sinarun Association; inextensive areas of Podzols and Histosols are included in the Kepayan and Sipitang Associations respectively.

The Tungku Association of Luvisols occurs on a coastal terrace of calcareous alluvium and the Tapang Association, in which Ferralsols are dominant, occurs mainly on alluvium derived from basic and ultrabasic igneous rocks.

BRANTIAN ASSOCIATION (12) 2818 km^2 (1080 mi^2)

This extensive association occurs in valleys on the west coast, in the Tenom, Keningau, Tambunan, Sook and Penawan Plains, on the north-east coast from the Bengkoka Peninsula to the Sugut estuary, in the Labuk estuary, along the Kinabatangan downstream from the confluence of the Kuamut and the Milian, along the southern coast of the Dent Peninsula, in the Semporna Peninsula and around Cowie Harbour. The association occurs on terraces of old alluvium at heights ranging from near sea level to over 450 m (1 475 ft) in the inland plains. The terraces are, in general, flat to slightly undulating, with short steep slopes in dissected parts. The alluvium is mainly medium to fine in texture but is occasionally coarse-textured and stony.

Orthic and Ferric Acrisols of the Paliu and Lumisir Families are dominant; Gleyic Acrisols of the Inanam Family occur on poorly drained flats and Gleyic Podzols of the Baiayo Family occur under inextensive areas of heath forest. In some places, notably in the Sook Plain, Orthic Ferralsols of the Benuou Family occur.

The association and its regional variations are described in Volumes 2, 3 and 4 and it also includes the following units:

1. The Tungau, Salut and Tanagian Series in the Tuaran District (Wilson, 1969b).
2. The Panataran, Labi and Rosok Series in the Kota Belud District (Wilson, 1969a).
3. The Tanagian, Nyamok, Langkon and Baiayo Series in the Kudat District (Belsham, 1969)
4. The Benoni Series in the Sugut District (McCredie, 1970a).
5. The Paliu, Baiayo and Tanjong Lipat Series in the Ranau District (McCredie, 1971).
6. The Paliu, Buis, Lumisir and Tapang Series in the Labuk valley (Hooper and Ives, 1964)

7. The Lucia, Locos Tagazo, Tanagian and Nyamok Series in the Dent Peninsula (Thomas 1967a).

8. The Gading, Limau and Lucia Families in the Semporna Peninsula (Paton, 1963).

SOOK ASSOCIATION (14) 424 km^2 (164 mi^2)

The Sook Association is extensive in the Sook and Penawan Plains and it also occurs in the Ruku Ruku valley, the Labuk estuary and in valleys in the Bangan and Maliau Basins. It occurs on valley floors and slightly dissected terraces of medium- to coarse-textured alluvium; the alluvial deposits are often tiered. Poorly drained Gleyic Acrisols of the Inanam Family are the dominant soils of the association; they are closely associated with Gleyic Podzols of the Baiayo Family. Humic and Dystric Gleysols and Dystric Histosols of the Guan, Koyah and Klias Families occur in the wettest sites. Orthic and Ferric Acrisols of the Paliu and Lumisir Families occur on well drained sites on somewhat higher terraces than the Gleyic Acrisols.

The association is described in Volumes 2 and 4.

SINARUN ASSOCIATION (16) 710 km^2 (274 mi^2)

The Sinarun Association occurs in the Tenom, Keningau, Tambunan and Penawan Plains and in the Labau Pandewan valleys. It occurs on dissected terraces, which are in the form of low hills with short, moderate to steep slopes. Parent materials comprise medium- to fine-textured, sometimes pebbly, alluvium overlying sandstone and mudstone; the alluvium often forms cappings on the hills with sandstone and mudstone outcropping on lower slopes.

Orthic Acrisols of the Paliu Family are dominant with Orthic Acrisols of the Tanjong Lipat Family on sandstone and mudstone. Poorly drained Gleyic Acrisols and Humic and Dystric Gleysols of the Inanam, Guan and Koyah Families occur on minor valley flats. Dystric Cambisols and Chromic Cambisols of the Kelawat and Mankawagu Families have been described on fans of stony alluvium in the Keningau and Tenom Plains.

The association is described in Volumes 2 and 4.

KEPAYAN ASSOCIATION (13) 278 km^2 (107 mi^2)

The Kepayan Association occurs on terraces in the Sook, Penawan, Keningau and Ranau Plains, near Sipitang, on Pulau Labuan, near Kota Belud, on Pulau Balambangan and Pulau Jambongan, in the Sugut estuary, near Telupid in the Labuk and Ruku Ruku valleys, at Sandakan and on the south coasts of the Dent and Semporna Peninsulas. The terraces are composed of tiered deposits of alluvium, with coarse-textured, sometimes pebbly, alluvium normally at the surface.

Gleyic Podzols of the Baiayo Family are the dominant soils and in many areas they are the only soils which occur. They also occur in association with Gleyic Acrisols of the Inanam Family and Orthic Podzols of the Silimpopon Family. Albic Arensols have been described on Pulau Labuan, near Sipitang, on Pulau Balambangan and on the south of the Dent Peninsula.

The association is described in Volumes 2, 3 and 4 and includes the following units:

1. The Baiayo Series near Kota Belud (Wilson, 1969a).

2. The Langkon, Baiayo and Balambangan Series (Belsham, 1969).

3. The Ranau Family near Ranau (McCredie, 1971).

4. The Karamuak Complex in the Labuk valley (Hooper and Ives, 1964).

5. The Serai Family in the Dent Peninsula (Thomas, 1967a).

6. The Kubota Family in the Semporna Peninsula (Paton, 1963).

SIPITANG ASSOCIATION (15)   38 km^2 (15 mi^2)

The Sipitang Association occurs at low altitudes on coastal terraces near Sipitang and above 1 200 m (4 000 ft) in the Maligan Range. It consists of poorly drained depressions of peat and coarse-textured alluvium.

Dystric Histosols of the Klias Family are the dominant soils with Gleyic Podzols and Albic Arensols of the Baiayo and Serai Families often on swamp fringes (see Volume 4).

TUNGKU ASSOCIATION (17)   82 km^2 (32 mi^2)

The Tungku Association is restricted to the eastern tip of the Dent Peninsula, where it occurs on a broad coastal terrace of calcareous alluvium underlain by coral.

Chromic Luvisols of the Terang Family are dominant in association with Gleyic Luvisols of the Lungpatau Family (see Volume 2). Calcic Luvisols of the Semporna Family and Rendzinas of the Loc Sambuang Family occur notably on the southern edge of the association where coral occurs at, or close to, the surface (see Loc Sambuang Series in Thomas, 1967a).

TAPANG ASSOCIATION (20)   193 km^2 (75 mi^2)

The Tapang Association occurs on low hills and terraces in the Labuk and Karamuak valleys. A notable occurrence is on the broad lowland linking the Labuk valley at Telupid with the Karamuak valley at Enteleben. The low hills are up to 30 m (100 ft) in amplitude with slopes of less than 15°; they are surrounded by slightly undulating terraces. The hills are formed of basic igneous rocks and the terraces are formed of alluvium derived from adjacent mountains of basic and ultrabasic igneous rocks.

Xanthic Ferralsols of the Tungau Family are the dominant soils on the terraces with Orthic Acrisols and Orthic Luvisols of the Kinabutan and Kobovan Families on low hills. Gleyic Luvisols of the Nangoh Family, Eutric Gleysols of the Bangawat Family and Dystric Histosols of the Klias Family occur on narrow, poorly drained, valley floors. Chromic Luvisols of the Mangkap Family occur notably on terraces in the Ensuan valley.

The association is described in Volume 2 and soils which are also included in the association are described as the Sinaputan, Nerelud, Kobovan, Baba, Bilai, Livodoi, Mengkadait and Ensuan Series in the Labuk valley (Hooper and Ives, 1964).

Soil associations on alluvium 5. Plateaus

The soils of 2 inextensive high level plateaus have been mapped as the Pinosuk and Tawai Associations.

PINOSUK ASSOCIATION (18)   75 km^2 (29 mi^2)

The Pinosuk Association occurs between Gunong Kinabalu and Ranau and includes both the Pinosuk Plateau, a piedmont feature with gentle slopes and the deeply dissected slopes between the plateau and the Sungai Liwagu. Parent materials consist of poorly consolidated, unsorted gravel in a sandy to clayey matrix and are considered to be solifluction deposits (Jacobson, 1970). These deposits overlie sandstone and mudstone, which are exposed in some valley sides and gorges. Terraces of alluvium probably derived from the solifluction deposits also occur in these valleys.

On the plateau itself the soils include Gleyic Podzols of the Baiayo Family, Humic and Dystric Gleysols of the Guan and Koyah Families and Gleyic Acrisols of the Inanam Family. Examples of profiles are contained in McCredie, (1971). On the steep slopes to the south of the plateau, Orthic and Gleyic Acrisols occur on gravels (Paliu and Inanam Families) and also on sandstone and mudstone (Tanjong Lipat and Gunong Alab Families).

TAWAI ASSOCIATION (19) 15 km^2 (6 mi^2)

The Tawai Association is restricted to the Tawai Plateau, which occurs at about 420 m (1 400 ft) on the Tawai Range south of Telupid. The plateau is level to gently sloping and much is swampy; its surface is formed of ironstone and alluvium..

The soils include Dystric Histosols of the Kaintano Family, Humic and Dystric Gleysols of the Guan and Koyah Families and Dystric Cambisols of the Meliau Family (see Volume 2).

Soil associations on mudstone/sandstone 1. Mudstone and minor sandstone

Four associations have been mapped on hills composed largely of mudstone with minor interbedded sandstone; there is a considerable overlap of soil units. The Lungmanis Association consists of very low hills and valley floors, the valley floors having soils similar to those described in the Kinabatangan Association. The Silabukan Association occurs on low hills with gentle slopes and the Kalabakan and Mawing Associations occur on moderate hills, the latter having slopes greater than 25^{o}.

LUNGMANIS ASSOCIATION (22) 1187 km^2 (458 mi^2)

The Lungmanis Association occurs in the Kinabatangan lowlands and in the Dent Peninsula, with major developments at Lungmanis, between the Sungai Koyah and the Sungai Tenegang Besar, at Dagat, in the Lumerau lowlands and in the Silabukan valley; It occurs on very low mudstone hills and broad flats of mainly fine-textured alluvium.

The association is essentially a combination of the Silabukan and Kinabatangan Association. Gleyic Acrisols and Gleyic Luvisols are dominant with the Inanam and Buran Families on the alluvial flats and the Masaum and Lunparai Families on the lower slopes of mudstone hills. Ferric and Orthic Acrisols and Ferric and Orthic Luvisols of the Natang, Kumansi, Lumerau and Lumpongon Families, respectively, also occur on the hills.

The association is described in Volume 2 and also includes the following units.

1. The Longtoi and Kumansi Series (Hooper and Ives, 1964).
2. The Tomanggong Familyin the south of the Dent Peninsula (Thomas, 1967a).

SILABUKAN ASSOCIATION (25) 574 km^2 (222 mi^2)

The Silabukan Association occurs in the Sandakan Peninsula and in the Kinabatangan lowlands. It occurs on low hills and valley floors, with amplitudes less than 30 m (100 ft) and slopes less than 15^{o}. The hills are formed of mudstone with minor interbedded sandstone; alluvium, which occurs on the valley floors is generally fine-textured.

The association is similar to the Lungmanis Association but the hills are slightly higher and the valley floors are much narrower. Because of this Ferric and Orthic Acrisols and Luvisols of the Batang, Kumansi, Lumerau and Lumpongon Families are dominant on the hills; Gleyic Acrisols and Gleyic Luvisols of the Masaum and Lunparai Families are confined to the minor valley floors and adjacent lower slopes of the mudstone hills.

The association is described in Volume 2 and it also includes the Longtoi, Kumansi and Kapuron Series (Hooper and Ives, 1964).

KALABAKAN ASSOCIATION (29) 816 km^2 (315 mi^2)

The Kalabakan Association occurs in the Kalabakan valley, the Inarat lowlands, the Kuamut valley, near Lamaga and Pintasan in the Kinabatangan valley, in the east of the Pensiangan District and in the Dent Peninsula. It occurs on moderate hills with amplitudes up to about 75 m (250 ft) and slopes generally between 10 and 20^o. The hills are formed dominantly from mudstone with minor interbedded sandstone.

Orthic Acrisols and Orthic Luvisols of the Kumansi and Lumpongon Families are dominant with sporadic Ferric Acrisols and Ferric Luvisols of the Batang and Lumerau Families. In areas where sandstone is more common Orthic Acrisols of the Tanjong Lipat Family occur in association with Dystric Cambisols of the Laab Family.

The association is described in Volumes 2, 3 and 4 and also includes the following units:

1. The Koung Series in the Dent Peninsula (Thomas, 1967a).
2. The Longupi, Rumidi and Kapuron Series near Lungmanis (Hooper and Ives, 1964).

MAWING ASSOCIATION (30) 254 km^2 (98 mi^2)

The Mawing Association has only been mapped in the west of the Tawau District, notably in the catchment area of the Sungai Kalabakan. It is formed on moderate hills, up to 75 m (250 ft) in amplitude, with narrow ridges, steep slopes and narrow valley floors; landslips are common. Parent materials consist of mudstone and sandstone, mudstone being dominant.

The soils, which are frequently shallow and stony, include Orthic Acrisols and Orthic Luvisols on mudstone (Kumansi and Lumpongon Families); Orthic Acrisols on sandstone and mudstone (Tanjong Lipat Family) and Dystric Cambisols on sandstone and mudstone (Laab Family) (see Volume 3).

Soil associations on mudstone/sandstone 2. Sandstone and mudstone

Seven associations have been mapped on hills and mountains composed largely of sandstone with interbedded mudstone; there is considerable overlap of soil units. The Dalit and Tengah Nipah Associations are both formed on moderate and low hills with slopes less than 20^o; the Dalit Association is extensive and consists largely of Orthic Acrisols, but in contrast the inextensive Tengah Nipah Association consists largely of Ferric Acrisols. The Lokan and Crocker Associations occur on very high hills and mountains respectively but both have similar ranges of soils with Acrisols and Cambisols dominant. The Maliau Association also contains many soils common to the Lokan and Crocker Associations, but it is formed on distinctive cuesta-form mountains with well defined dip slopes on which Podzols sometimes occur. Extensive areas of Podzols are separated as the Serudong Association. The Trusmadi Association occurs generally above 1 200 m (4 000 ft) and consists largely of Acrisols, Podzols and Gleysols; it normally occurs above the Crocker Association.

DALIT ASSOCIATION (31) 3144 km^2 (1212 mi^2)

The Dalit Association is extensive with major developments on the west coast from Sipitang to Kota Belud, in the interior plains notably between Keningau, Sook and Dalit and north-east of Ranau, in the Mananam Plain, in the Karamuak, Labuk Tungud and and Ruku Ruku valleys and between the Sungai Sugut and the Sungai Kanibongan. It occurs on moderate hills and minor valley floors, with amplitudes up to about 75 m (250 ft) and slopes generally between 10 and 20^o. Sandstone and mudstone are the dominant parent materials with medium- to coarse-textured alluvium on the minor valley floors.

Orthic Acrisols of the Tanjong Lipat Family are dominant on the hills, with sporadic occurrences of Orthic Acrisols of the Kapilit and Kumansi Families and Ferric Acrisols of the Sipit Family. Gleyic Acrisols of the Gunong Alab Family occur on some lower slopes adjacent to the valley floors. Gleyic Acrisols of the Inanam Family and Dystric Gleysols of the Koyah Family are dominant on the alluvium of the valley floors.

The association and its regional variations are described in Volumes 2, 3 and 4 and the following units are also included:

1. The Lantiggi and Kota Belud Series in the Kota Belud District (Wilson, 1969a)
2. The Tanjong Lipat and Boititian Series in the Kudat District (Belsham, 1969) and in the Sugut and Ranau Districts (McCredie, 1970a and 1971).
3. The Tendu Batu and Rumidi Series in the Labuk valley area (Hooper and Ives, 1964).

TENGAH NIPAH ASSOCIATION (32) 524 km^2 (202 mi^2)

The Tengah Nipah Association occurs mainly in the west of the Dent Peninsula and also in the Tengah Nipah area to the east of Lahad Datu. It is formed on moderate hills of sandstone and mudstone; slopes are generally between 10 and 20^o. Narrow valley floors of mainly fine-textured alluvium are also included.

Ferric Acrisols of the Sipit Family are dominant with minor Orthic Acrisols of the Tanjong Lipat Family; it is for this reason that the association is separated from the Dalit Association, in which Orthic Acrisols are dominant. Gleyic Acrisols and Gleyic Luvisols of the Inanam and Buran Families occur on alluvium (see Volume 2 and the Tengah Nipah series in Thomas, 1967a).

LOKAN ASSOCIATION (39) 8436 km^2 (3254 mi^2)

The Lokan Association is extensive throughout Sabah, with major developments in the foothills of the Crocker Range on the west and north-east coasts, around the interior plains, in the catchment area of the Sungai Labuk above Telupid, between the Mananam Plain and the Maliau Basin, in the east of the Pensiangan District and in the Lokan Peneplain. It occurs on very high hills with amplitudes up to 300 m (1 000 ft) and slopes often greater than 25^o; hill crests are often very narrow. The hills are formed of interbedded sandstone and mudstone.

Orthic Acrisols are widespread and the Tanjong Lipat Family is dominant; soils of the Kapilit and Kumansi Families occur sporadically. Dystric and Chromic Cambisols of the Laab, Antulai and Luasong Families occur on unstable slopes with Lithosols and rock outcrops.

The Lokan Association is described in Volumes 2, 3 and 4 and includes the following units described in other regional surveys:

1. The Tanjong Lipat, Kota Belud and Lantiggi Series in the Tuaran District (Wilson, 1969b) and the Kota Belud and Lantiggi Series in the Kota Belud District (Wilson 1969a).

2. The Tanjong Lipat, Boititian and Kenipir Series in the Kudat District (Belsham, 1969).

3. The Boititian and Tanjong Lipat Series in the Tanau, Labuk and Sugut Districts (McCredie 1970a and 1971).

4. The Boititian, Kenipir and Togoron Series in the Labuk valley area (Hooper and Ives, 1964).

CROCKER ASSOCIATION (47) 17 782 km^2 (6 870 mi^2)

The Crocker Association is the most extensive association in Sabah and it is almost continuous from the Kudat and Bengkoka Peninsulas in the north-east to the Kalimantan boundary in the south. It occurs on extensive mountain ranges, notably the Crocker Range and the associated Sir James Brooke, Witti and Maitland Ranges and the Brassey Range. Amplitudes are in excess of 300 m (1 000 ft) and slopes are normally greater than 25^{o}; ridge crests and valley bottoms are narrow and landslips are common. The mountains are formed of interbedded sandstone and mudstone.

The association includes Orthic Acrisols of the Tanjong Lipat, Kapilit and Kumansi Families, Dystric and Chromic Cambisols of the Laab, Antulai and Luasong Families and Lithosols. These soils are indentical to those in the Lokan Association but the Crocker Association is separated because of the major landform change from high hills to mountains and the associated increase of Cambisols and Lithosols. The association is described in Volumes 2, 3 and 4 and includes the following units mapped in other regional surveys:

1. The Tanjong Lipat, Kota Belud and Lantiggi Series in the Tuaran District (Wilson, 1969b) and the Kota Belud and Lantiggi Series in the Kota Belud District (Wilson, 1969b).

2. The Tanjong Lipat, Boititian and Kenipir Series in the Kudat District (Belsham, 1969).

3. The Boititian and Tanjong Lipat Series in the Ranau, Labuk and Sugut Districts (McCredie, 1970a and 1971).

4. The Boititian and Kenipir Series in the Labuk valley area (Hooper and Ives, 1964).

MALIAU ASSOCIATION (48) 8 543 km^2 (3 300 mi^2)

The Maliau Association is extensive in the south of the State occurring notably in the Maliau and Bangan Basins, in the west of the Tawau District and in the south of the Sipitang and Tenom Districts; it also occurs in the Kudat, Bengkoka and Sandakan Peninsulas, on Pulau Jambongan and on the Obar Hills between the estuaries of the Labuk and Sugut. It occurs at altitudes ranging from near sea level to over 1 650 m (5 500 ft), on hill and mountain cuestas with series of steep scarp slopes and long gentle dip slopes; the dip slopes are occasionally short and steep where the strata are steeply inclined. The parent materials comprise interbedded sandstone and mudstone; sandstone is dominant and often occurs at the surface of complete dip slopes.

Orthic Acrisols of the Kapilit and Tanjong Lipat Families occur on the scarpslopes, but Dystric Cambisols of the Antulai Family are dominant on the steepest slopes in association with Lithosols and rock outcrops. The Kapilit and Tanjong Lipat Families also occur on the dip slopes in association with Gleyic and Orthic Podzols of the Pa Sia and Sibuga Families. Orthic Acrisols are replaced by Gleyic Acrisols and Humic Gleysols of the Gunong Alab and Kidukarok Families above about 1 200 m (4 000 ft) and Distric Histosols of the Kaintano Family occur on many ridges.

The association is described in Volumes 2, 3 and 4 and also includes the following units mapped in other regional surveys.

1. The Obar and Boititian Series in the Obar Hills and on Pulau Jambongan (McCredie, 1970a).

2. The Boititian, Obar and Kenipir Series in the Kudat and Bengkoka Peninsulas (Belsham, 1969).

SERUDONG ASSOCIATION (49) 213 km^2 (82 mi^2)

The Serudong Association occurs in the Maliau Basin, in the south-east of the Pensiangan District and in the headwaters of the Sungai Serudong in the west of the Tawau District. It occurs on the dip slopes of mountain cuestas, which are formed largely of sandstone with minor interbedded mudstone; heath forest is the natural vegetation.

Gleyic Podzols of the Pa Sia Family are the dominant soils in association with Dystric Histosols of the Kaintano Family. Orthic Acrisols of the Kapilit Family and Dystric Cambisols of the Antulai Family occur sporadically.

The association is described in Volumes 2, 3 and 4.

TRUSMADI ASSOCIATION (50) 1 048 km^2 (424 mi^2)

The Trusmadi Association occurs above about 1 200 m (4 000 ft) on the Crocker Range and extensively on the Trusmadi Range reaching 2 580 m (8 600 ft) at the summit of Gunong Trusmadi. Slopes are steep and often sheer and the summit crests are narrow. Sandstone and mudstone are the main parent materials and the Trusmadi Formation, which forms the Trusmadi Range, also includes mildly metamorphosed slates and subordinate beds of quartzite.

Orthic and Gleyic Acrisols of the Tanjong Lipat, Kumansi and Gunong Alab Families and Humic Acrisols of the Kiau Family occur below about 1 350 m (4 500 ft). Above this height Gleyic Podzols of the Pa Sia Family become dominant and in moss forests above about 1 950 m (6 500 ft) they occur in close association with Humic Gleysols of the Kidukarok Family and Dystric Histosols of the Kaintano Family. Lithosols occur on many of the steep slopes.

The association is described in Volumes 2 and 4 and also include the Tudan, Kiau and Gunong Alab Series on the Crocker Range (Wilson, 1969a).

Soil associations on mudstone/sandstone 3. Mudstone, sandstone and miscellaneous rocks

Six complex associations have been mapped on slump formations consisting of mudstone, sandstone and miscellaneous rocks. There is a wide range of soil units in each association and there is a considerable overlap between associations. The Rumidi Association occurs on low hills with mudstone the dominant parent material. In contrast, sandstones are more common in the Kretam Association which occurs on moderate hills. The Sipit Association is similar to the Rumidi Association and should probably be combined with it, but the Dagat Association is distinctive, because its soils are formed mainly on tuffaceous rocks. The Bang and Gumpai Associations occur on hills and mountains and again, because of the wide ranges and similarities of the soils contained, should probably be combined.

RUMIDI ASSOCIATION (26) 2 166 km^2 (836 mi^2)

The Rumidi Association occurs in the Sandakan and Kinabatangan Districts, extending from the Labuk estuary in the north-west to the Sungai Segama in the south and south-east. It also occurs in the Kudat Peninsula and on Pulau Banggi. It occurs on low hills and narrow alluvial flats with amplitudes up to 30 m (100 ft) and slopes of less than 15°. The association is formed on slump deposits in which mudstone is dominant; fine- textured alluvium is dominant on the alluvial flats.

Because of the diversity of parent materials, which occur in the slump deposits, a wide range of soils occurs in the association. Ferric Acrisols and Ferric Luvisols of the Batang, Sipit and Lumerau Families are dominant on mudstone and they occur in association with Orthic Acrisols and Orthic Luvisols of the Kumansi, Tanjong Lipat and Lumpongon Families on well drained sites and Gleyic Acrisols and Gleyic Luvisols of the Masaum and Lunparai Families on lower slopes and flats. These soils are similar to those in the Silabukan Association, but the Rumidi Association includes in addition, Acrisols and Luvisols which are formed on outcrops of miscellaneous rocks and which collectively constitute an important part of it; they are locally dominant. Regional variations are described in Volumes 2 and 4 and the following units are included in the association.

1. The Rumidi, Tanjong Lipat, Binuang and Boititian Series and the Limbuak Variants (Belsham, 1969).

2. The Longtoi, Kumansi, Rumidi and Kapuron Series south of the Labuk estuary (Hooper and Ives, 1964).

3. The Kayan, Tengah Nipah, Beeston, Lamak and Mensuli series in the Dent Peninsula (Thomas, 1967a).

KRETAM ASSOCIATION (33) 3 256 km^2 (1 254 mi^2)

The Kretam Association is extensive in the Sandakan and Kinabatangan Districts with major developments north of Lungmanis, south of Sandakan Harbour and continuously from Kuamut in the west to the lower Segama in the east. It also occur sporadically in the Tawau District, west of Darvel Bay, on Pulau Banggi and on Pulau Tiga off the west coast. It occurs on moderate hills with amplitudes generally up to 75 m (250 ft) and slopes between 10 and 20°. The soils are formed on slump deposits consisting of sandstone, mudstone and miscellaneous rocks; sandstone is generally dominant.

On sandstone and mudstone Orthic Acrisols of the Tanjong Lipat Family are dominant; Ferric Acrisols of the Sipit Family are of limited extent. In addition a range of Acrisols, Luvisols and Cambisols occur on outcrops of miscellaneous rocks and of these, igneous rocks, tuffaceous rocks and chert are locally dominant.

The association is described in Volumes 2, 3 and 4 and the following units are also included.

1. The Limbuak Variants and Binuang Series on Pulau Banggi (Belsham, 1969).

2. The Rumidi and Kapuron Series south of the Labuk estuary (Hooper and Ives, 1964).

3. The Tengah Nipah, Lamak, Kayan, Mensuli and Koung Series in the south of the Dent Peninsula (Thomas, 1967a).

SIPIT ASSOCIATION (27) 316 km^2 (122 mi^2)

The Sipit Association occurs in the Semporna Peninsula, where it extends from west of the Sungai Kalumpang eastwards across the Sungai Sipit to the Sungai Pegagau. It is formed on a coastal platform which has been dissected into low hills, with slopes mainly less than 15^o, and narrow entrenched valleys. Parent materials comprise mudstone, sandstone and miscellaneous rocks of the Chert-Spilite and Kalumpang Formations.

Ferric Acrisols of the Sipit Family are probably the dominant soils but Orthic Acrisols of the Dagat Family and Orthic Luvisols of the Kobovan Family have been described on rhyolitic tuffs and andesitic ashes respectively (see the Sipit Family in Paton, 1963).

DAGAT ASSOCIATION (35) 231 km^2 (89 mi^2)

The Dagat Association occurs in the Dent Peninsula, notably west and south of Dagat and close to the coastline near Tungku. It occurs on moderate hills with slopes mainly between 10 and 20^o, which are formed from slump deposits in which tuffaceous rocks, including tuff and tuffite, sandstone and mudstone are dominant.

Chromic and Orthic Luvisols of the Libong and Talid Families and Orthic Acrisols of the Dagat Family occur on the tuffaceous rocks; the Libong Family is dominant between the Sungai Segama and the Sungai Tabin (see Volume 2) and also in the headwaters of the Tabin and near Tungku (see Kayan series, in Thomas, 1967).

Orthic Luvisols of the Lumpongon Family and Orthic Acrisols of the Tanjong Lipat Family occur on mudstone and sandstone notably to the east of the Sungai Tabin.

BANG ASSOCIATION (40) 899 km^2 (347 mi^2)

The Bang Association occurs in the Lahad Datu and Tawau Districts. In the Lahad Datu District it occurs in the headwaters of the Sungai Segama and its tributaries; in the Tawau District it occurs sporadically from the Kalabakan catchment in the west, across the Semporna Peninsula to Pulau Timbun Mata in the east. It occurs on very high hills with amplitudes up to 300 m (1 000 ft); slopes are generally between 15 and 25^o, but many are steeper. Parent materials consist largely of slump deposits in which sandstone and mudstone are dominant; chert, tuffaceous rocks, limestone and intermediate, basic and ultrabasic igneous rocks also occur.

Orthic Acrisols of the Tanjong Lipat and Kumansi Families, Ferric Acrisols of the Sipit Family and Dystric Cambisols of the Laab Family occur on sandstone and mudstone. The soils which are developed on the miscellaneous rocks include Acrisols, Luvisols, Cambis and Lithosols. Some areas mapped as the Cook Family (Paton, 1963) are included in this association; Paton described examples of largely skeletal soils formed on ultrabasic igneous rocks and limestone in addition to interbedded sandstones and shales. For information on the association in the western parts of the Tawau and Lahad Datu Districts the reader is referred to Volume 3.

GUMPAL ASSOCIATION (46) 2 885 km^2 (1 120 mi^2)

The Gumpal Association is extensive in the Lahad Datu and Tawau Districts, notably in the Dent Peninsula and in the catchment areas of the Bole, Brantian, Gumpal, Merotai and Tingkayu rivers. It occurs on hills and mountains with steep slopes, often greater than 25^o, and narrow ridges; landslips are common. The soils are formed mainly on slump deposits consisting of sandstone, mudstone and tuffaceous rocks; other rocks such as chert and various igneous rocks may be locally dominant.

Orthic Acrisols of the Tanjong Lipat Family, Dystric Cambisols of the Laab Family and Lithosols occur on the sandstone and mudstone; the Laab Family occurs on the unstable slopes and Lithosols are closely associated with rock outcrops. On tuffaceous rocks, which are dominant in the Dent Peninsula, the soils include Chromic and Orthic Luvisols of the Libong and Talid Families, Orthic Acrisols of the Dagat Family, Dystric and Eutric Cambisols of the Tenggara and Hatton Families and Lithosols; the Cambisols occur on unstable slopes and Lithosols are associated with rock outcrops. Acrisols, Luvisols, Cambisols and Lithosols are formed on miscellaneous rocks which are locally dominant.

The association and its regional variations are described in Volume 2 and 3 and it also includes the following units mapped in other regional surveys:

1. The Mensuli, Juak and Binuang Series and the Limbuak Variants on Pulau Banggi and east of Marudi Bay (Belsham, 1969)

2. The Kayan Series in the Dent Peninsula (Thomas, 1967a)

3. The Cook, Malatai and Kalumpang Families in the Semprona Peninsula (Paton, 1963).

Soil associations on limestone

Two inextensive associations, the Semporna and Gomantong Associations have been mapped on limestone.

SEMPORNA ASSOCIATION (21) 217 km^2 (84 mi^2)

The Semporna Association occurs in the east of the Dent and Semporna Peninsulas and on adjacent islands. It occurs on flats and very low hills, with slopes generally less than 5^o, formed from coralline limestone.

Chromic and Calcic Luvisols of the Tegupi and Semporna Families are dominant with Rendzinas of the Loc Sambuang Family on outcrops of coralline limestone.

The association is described in Volume 2; areas mapped as the Semporna Family (Paton, 1963) are also included in the association.

GOMANTONG ASSOCIATION (38) 45 km^2 (17 mi^2)

The Gomantong Association occurs notably at Gomantong, Gunong Madai and Batu Punggul and on Pulau Balambangan and Pulau Banggi. It occurs on outcrops of limestone with steep, often sheer, slopes.

Rendzinas of the Loc Sambuang Family occur in close association with rock outcrops on the steep slopes and Calcic Luvisols of the Semporna Family are developed in pockets and on narrow flats.

The association is described in Volumes 2 and 4 and the following units are also included.

1. The Balambangan Karst and Rock Associations on Pulau Balambangan (Belsham, 1969)

2. The Kapor and Kaporan Series on Pulau Mantanani Besar and Pulau Mantanani Kechil (Wilson, 1969a)

3. The Madai Family in the Lahad Datu District (Thomas, 1967a) and the Madai Sub-family in the Semporna Peninsula (Paton, 1963).

Soil associations on ultrabasic igneous rocks

The Kinabalu Association is the only association mapped on acid igneous rocks.

KINABALU ASSOCIATION (51) 127 km^2 (49 mi^2)

The Kinabalu Association occurs notably on Gunong Kinabalu (Frontispiece) and also on less imposing mountains to the east. Gunong Kinabalu 4 101 m (13 455 ft) is the highest mountain in south-east Asia; it has a summit with isolated peaks and pinnacles rising steeply above a general plateau level of 3 650-3 800 m (12 000-12 500 ft). Its topography results from the presence of an ice-cap during the Pleistocene period and glacial features include cirques, hanging valleys, valleys with U-shaped cross-section, markings such as striations and grooves and steep cliffs probably representing ice falls. There are many steep cliffs particularly on the west side of the mountain where they are up to 1 500 m (5 000 ft) high. The mountain is formed of acid igneous rocks, notably hornblende adamellite and biotite granodiorite.

Askew (1964) describes soils on granodiorite all of which have umbric horizons; they include rankers with umbric horizons resting directly on rock slabs (Rankers of the Kinabalu Family), soils with thin iron pans underlying umbric horizons (Placic Podzols of the Mesilau Family) and soils superficially similar to temperate brown earths, with thick, strong brown horizons underlying umbric horizons (Humic Cambisols of the Mantaki Family).McCredie (1971) and Wilson (1969a) also describe Humic Cambisols on steep slopes of granodiorite and granite. In addition Askew (1964) and Wilson (1969a) describe skeletal soils with fibrous litter layers (Dystric Histosols of the Kaintano Family) in exposed positions. Lithosols cover large parts of the association and occur in close association with rock outcrops and with blocks and slabs of rock.

Soil associations on intermediate igneous rocks

Three associations have been mapped on predominantly intermediate igneous rocks. Of these the Apas and Kennedy Bay Associations are very similar and should probably be combined; they are both formed on moderate to high hills in contrast to the Wullersdorf Association, which is formed on mountains.

APAS ASSOCIATION (28) 249 km^2 (96 mi^2)

The Apas Association is restricted to the Semporna Peninsula, where it occurs extensively north of Tawau, in the catchment of the Sungai Apas, north of the Kalumpang estuary and to the south of the river in the upper Kalumpang valley. Parent materials comprise andesitic and dacitic lavas and ashes, which have been dissected into ridges with short steep slopes separated by narrow valleys up to 45 m (150 ft) deep.

The soils include Rhodic Ferralsols of the Apas Family, Orthic Acrisols of the Kinabutan Family and Eutric Cambisols of the Quarry Family, which were originally described as the Apas, Kinabutan and Quarry sub-families by Paton (1963).

KENNEDY BAY ASSOCIATION (36) 457 km^2 (176 mi^2)

The Kennedy Bay Association occurs extensively to the north and east of Lahad Datu and on the Bagahak Range north-east of Kennedy Bay.

The Bagahak Range consists of hills and ridges with amplitudes rarely exceeding 150 m (500 ft). The hills are largely formed of 'pyroclastic boulder conglomerate' of the Tungku Formation (Haile and Wong 1965) and the soils are dominantly Eutric Cambisols of the Tinagat Family, Orthic Luvisols of the Kobovan Family and Orthic Acrisols of the Kinabutan Family (see Tinagat, North Road and Segama Families; Thomas, 1967a). Rhodic Ferralsols of the Apas Family occur particularly on basic volcanic ash on lower slopes in the west (see Bakapit Family; Thomas, 1967a).

To the east and north of Lahad Datu the hills are also formed of rocks of the Tungku Formation with tuffaceous sandstone and conglomerate dominant. In this area Dystric Cambisols of the Durikong Family occur on conglomerates composed largely of chert (see Durikong Family: Thomas, 1967a) and they form in association with Chromic Luvisols of the Libong Family on basic sandstone (see Kayan Family; Thomas, 1967a) and Eutric Cambisols of the Tinagat Family).

North of the Segama, Ferric Acrisols of the Batang and Sipit Families are formed on mudstone, bentonitic shale, (see Koung Family; Thomas, 1967a) and sandstone in association with Orthic Luvisols of the Kobovan Family and Chromic Luvisols of the Libong Family.

WULLERSDORF ASSOCIATION (45) 592 km^2 (228 mi^2)

The Wullersdorf Association is extensive to the north of Tawau and it also occurs to the east of the Kalumpang estuary. It occurs on mountain ranges with prominent peaks including Magdalena, Lucia, Maria and Wullersdorf. The mountains are formed of a variety of parent materials broadly described as intermediate and acid igneous rocks; Paton (1963) describes soils on andesitic ashes, rhyolitic lavas and dacitic lavas and ashes.

Eutric Cambisols of the Quarry and Bombalai Families and Lithosols are the dominant soils, with Humic Gleysols of the Wullersdorf Family at high altitudes under 'mossy forest' (see Wullersdorf sub-family of the Tajong Family; Paton 1963).

Soil associations on acid igneous rocks

Seven associations are mapped on basic igneous rocks. The Mentapok Association occurs extensively on mountain ranges and should probably include both the Tinagat and Beruang Associations. The Malubok Association is also very similar to the Mentapok Association but it also contains a range of soils formed on miscellaneous rocks. The Tiger, Table and Orchid Plateau Associations are, however, distinctive; the Tiger Association occurs on extinct volcanoes and is surrounded by the Table Association on lava flows; the Orchid Plateau Association occurs on the Orchid Plateau at a height of about 660 m (2 200 ft) a.s.l.

MENTAPOK ASSOCIATION (42) 2 272 km^2 (877 mi^2)

The Mentapok Association is extensive on mountain ranges composed of basic and intermediate igneous rocks. It occurs notably on the Meliau Range, on ranges to the east and west of the Mananam Plain, on the watershed of the Segama and Kinabatangan and most extensively in the mountainous half of the Lahad Datu District to the west of Lahad Datu. Slopes are steep and often sheer and ridge crests are narrow.

The association consists essentially of Luvisols, Cambisols and Lithosols. Orthic and Chromic Luvisols of the Kobovan and Beeston Families are dominant with Chromic and Eutric Cambisols of the Kawa and Bombalai Families on very steep slopes and ridge crests. Dystric Cambisols of the Nerelud Family and Orthic Acrisols of the Kinabutan Family occur sporadically. Lithosols are associated with extensive areas of rock outcrop.

The association is described in Volumes 2 and 4 and areas mapped as the Nerelud, Kinarut and Tungud Series in the Meliau Range and Bidu Bidu Hills (Hooper and Ives, 1964) and the Silam, Beruang and Sapa Labang Series west of Lahad Datu (Thomas 1967) are also included.

TINAGAT ASSOCIATION (43) 339 km^2 (131 mi^2)

The Tinagat Association occurs in the Semporna Peninsula particularly to the east of the Kalumpang valley, south-west of Semporna and on Pulau Timbun Mata; it also occurs on Bukit Tinagat, to the north-east of Tawau and to the south of the river in the upper Kalumpang valley. The association occurs on mountains and hills of basic and intermediate igneous rocks and includes Eutric Cambisols of the Hatton and Bombalai Families, Ferric Luvisols of the Besar Family and Lithosols. The soils were originally described by Paton (1963), who quotes profiles on red tuff, basic volcanic agglomerate, dolerite and diorite, which were classified as sub-families of the Besar Family.

BERUANG ASSOCIATION (34) 66 km^2 (25 mi^2)

The Beruang Association occurs in the Sapagaya valley to the west of Lahad Datu. It occurs on basic igneous rocks on hills with moderate to steep slopes. This association is inadequately documented and the only soil which has been described is a Ferric Acrisol of the Beruang Family (see Beruang Series, Thomas, 1967a). The association however, is closely related to the Mentapok Association and will undoubtedly include Chromic and Orthic Luvisols of the Beeston and Kobovan Families, Eutric Cambisols of the Bombalai Family and Lithosols.

MALUBOK ASSOCIATION (44) 848 km^2 (327 mi^2)

The Malubok Association occurs on the mountains which form part of the watershed of the Segama and the Kinabatangan and it also occurs on the flanks of Gunong Tambuyukon. The parent materials are complex but basic and intermediate igneous rocks are probably dominant; chert is locally dominant and there are less common occurrences of ultrabasic igneous rocks and sandstone.

The soils comprise those described in the Mentapok, Bidu Bidu and Crocker Associations. In addition Chromic and Dystric Cambisols of the Juak and Durikong Families and Orthic Acrisols of the Mensuli Family occur on chert. The association is described in Volumes 2 and 3 and also includes areas of heterogeneous rock debris and soils of the Tanjong Lipat and Gunong Alab Series on Gunong Tambuyukon (McCredie 1971).

TIGER ASSOCIATION (37) 9 km^2 (3 mi^2)

The Tiger Association occurs on extinct volcanoes in the Semporna Peninsula to the north of Tawau and at Quoin Hill. There are 3 extinct volcanoes north of Tawau, namely Gunong Tiger, Gunong Bombalai and Middle Hill. Gunong Bombalai still retains the characteristic forms of a volcano with a small breached crater on its southern flank; Quoin Hill is a small steep-sided volcanic cone with a crater about 275 m (900 ft) in diameter breached on its eastern side (Kirk, 1962). The soils are formed on basalt lavas and include Chromic and Eutric Cambisols of the Kawa and Bombalai Families respectively (see Bombalai Family, in Paton 1963).

TABLE ASSOCIATION (23) 201 km^2 (78 mi^2)

The Table Association occurs in the Semporna Peninsula to the north of Tawau, in the Quoin Hill area and at Mostyn. North of Tawau the association occurs on basalt lava flows, with pronounced terrace features, which are believed to mark the original edges of successive flows. At Mostyn the lavas occupy an extensive plateau area and basalt boulders form low knolls. In general the lavas are weathered to depths exceeding 20 ft (Kirk, 1962). The soils, originally described on Table Estate as the Table Family (Paton, 1963) include Xanthic and Orthic Ferralsols of the Jarangan and Table Families.

ORCHID PLATEAU (24) 37 km^2 (14 mi^2)

The Orchid Plateau Association is restricted to the Orchid Plateau in the west of the Lahad Datu District. The plateau occurs at a height of 660 m (2 200 ft) and consists of low hills with level to slightly convex tops and moderately steep valley sides. Parent materials comprise basic and intermediate igneous rocks.

Orthic Acrisols of the Kinabutan Family are dominant, with minor occurrences of Chromic Luvisols of the Beeston Family and Orthic Luvisols of the Kobovan Family (see Volume 3).

Soil associations on ultrabasic igneous rocks

The Bidu Bidu Association is the only association mapped on ultrabasic igneous rocks. The Tawai and Binalik Associations which also have soils formed on parent materials derived from ultrabasic igneous rocks have been described in the preceding paragraphs.

BIDU BIDU ASSOCIATION (41) 1 821 km^2 (703 mi^2)

The Bidu Bidu Association occurs on mountains and hills of ultrabasic igneous rocks. Mountains include those to the east and west of Gunong Kinabalu, Gunong Tambuyukon, the Meliau Range, the Bidu Bidu Hills, the Tawai Range, Gunong Rara, Gunong Silam and various peaks in the headwaters of the Segama and on the watershed of the Segama and the Kinabatangan. The association also includes areas of low hills notably in the lower Labuk valley and sporadically in the Kinabatangan lowlands.

Rhodic and Orthic Ferralsols of the Pinianakan and Ambun Families are the dominant soils; they are formed on colluvial deposits on sites ranging from steep upper slopes and crests to lower slopes. Orthic and Chromic Luvisols of the Tingkayu and Malawali Families occur on steep slopes in association with Chromic, Eutric and Dystric Cambisols of the Silad, Binuang and Meliau Families; Lithosols occur on rock outcrops. The association is described in Volumes 2 and 3 and the following units described in other regional surveys are also included.

1. The Pinianakan, Tawai, Malawali and Meliau Series on the Meliau Range, Bidu Bidu Hills and in the lower Labuk valley (Hooper and Ives, 1964).
2. The Tingkayu Family in the Semporna Peninsula (Paton, 1963).
3. The Binuang, Hujong and Pinianakan Families in the Gunong Silam area (Thomas, 1967a).
4. The Binuang Association on Pulau Malawali (Belsham, 1969).
5. The Meliau, Pinianakan, Minitidnuk and Kilumbun Series on Tambuyukon and Kinabalu (Wilson 1969a).

Publications of the Land Resources Division

These publications have a restricted distribution and are not available to booksellers. The Division makes a report on each completed project. The report is published as a *Land Resource Study* or *Technical Bulletin* only with the consent of the government concerned.

BAWDEN M G and LANGDALE-BROWN I	1961	An aerial photographic reconnaissance of the present and possible land use in the Bamenda Area, Southern Cameroons.*
BAWDEN M G and STOBBS A R	1963	The land resources of Eastern Bechuanaland.
LANGDALE-BROWN I and SPOONER R J	1963	The land use prospects of Northern Bechuanaland.*
BAWDEN M G (Ed)	1965	Some soils of Northern Bechuanaland with a description of the main vegetation zones.

LAND RESOURCE STUDIES

SPOONER R J and JENKIN R N	1966	The development of the Lower Mgeta River Area of the United Republic of Tanzania. *Land Resource Study* No. 1.
BAWDEN M G and TULEY P	1966	The land resources of Southern Sardauna and Southern Adamawa Provinces, Northern Nigeria. *Land Resource Study* No. 2.*
BAWDEN M G and CARROLL D M	1968	The land resources of Lesotho. *Land Resource Study* No. 3.*
JENKIN R N and FOALE M A	1968	An investigation of the coconut-growing potential of Christmas Island. Volume 1, The environment and the plantations. Volume 2, Appendixes. *Land Resource Study* No. 4.
BLAIR RAINS A and McKAY A D	1968	The Northern State Lands, Botswana. *Land Resource Study* No. 5.

* Out of print.

HILL I D	1969	An assessment of the possibilities of oil palm cultivation in Western Division, The Gambia. *Land Resource Study* No. 6.
VERBOOM W C and BRUNT M A	1970	An ecological survey of Western Province, Zambia, with special reference to the fodder resources. Volume 1, The environment, Volume 2, The grasslands and their development. *Land Resource Study* No.8.
AITCHISON P J and GLOVER P E	1970	The land resources of North East Nigeria. Volume 2, Tsetse and Trypanosomiasis. *Land Resource Study* No. 9*.
JOHNSON M S	1971	New Hebrides Condominium, Erromango Forest Inventory. *Land Resource Study* No. 10.
AITCHISON P J BAWDEN M G CARROLL D M GLOVER P E KLINKENBERG K LEEUW P N de and TULEY P	1972	The land resources of North East Nigeria. Volume 1, The environment. *Land Resource Study* No. 9.
BAWDEN M G CARROLL D M and TULEY P	1972	The land resources of North East Nigeria. Volume 3, The land systems. *Land Resource Study* No. 9.
LEEUW P N de LESSLIE A and TULEY P	1972	The land resources of North East Nigeria. Volume 4, Present and potential land use. *Land Resource Study* No. 9.
TULEY P (Ed)	1972	The land resources of North East Nigeria. Volume 5, Appendixes and tables. *Land Resource Study* No. 9.
BLAIR RAINS A and YALALA A M	1972	The Central and Southern State Lands, Botswana. *Land Resource Study* No.11*.
BERRY M J and HOWARD W J	1973	Fiji Forest Inventory Volumes 1-3. *Land Resource Study* No.12.
JOHNSON M S and CHAFFEY D R	1973	Forest Inventory of Part of the Mountain Pine Ridge, Belize. *Land Resource Study* No.13.
JOHNSON M S and CHAFFEY D R	1973	An Inventory of the Chiquibul Forest Reserve, Belize. *Land Resource Study* No.14.
JOHNSON M S and CHAFFEY D R	1974	Forest Inventory of the Pine Forests of the Southern Coastal Plains, Belize, *Land Resource Study* No.15.
HENRY P W T	1974	Pine Forests of the Bahamas, *Land Resource Study* No. 16.
BERRY M J LAURENCE J F MAKIN M J and WADDAMS A E	1974	Development potential of the Nawalparasi area of Nepal. *Land Resource Study* No. 17.

* Out of print

TECHNICAL BULLETINS

CARROLL D M and BASCOMB C L	1967	Notes on the soils of Lesotho. *Technical Bulletin* No. 1.
PIGGOTT C J	1968	A soil survey of Seychelles. *Technical Bulletin* No. 2*.

LAND RESOURCE BIBLIOGRAPHIES

POSNETT N W and REILLY P M comp.	1971	Bahamas. *Land Resource Bibliography* No.1.
POSNETT N W REILLY P M and WHITFIELD P comp.	1971	Nigeria. *Land Resource Bibliography* No. 2.
POSNETT N W and REILLY P M comp.	1973	Belize (British Honduras). *Land Resource Bibliography* No. 3.
POSNETT N W and REILLY P M comp.	1973	Fiji. *Land Resource Bibliography* No. 4.
POSNETT N W and REILLY P M comp.	1974	New Hebrides and New Caledonia. *Land Resource Bibliography* No. 5.
REILLY P M comp.	1974	Nepal. *Land Resource Bibliography* No. 6.

* Out of print

Produced in England by Her Majesty's Stationery Office, Reprographic Centre, Basildon

R 78831/10099/12 750 1/75 TP