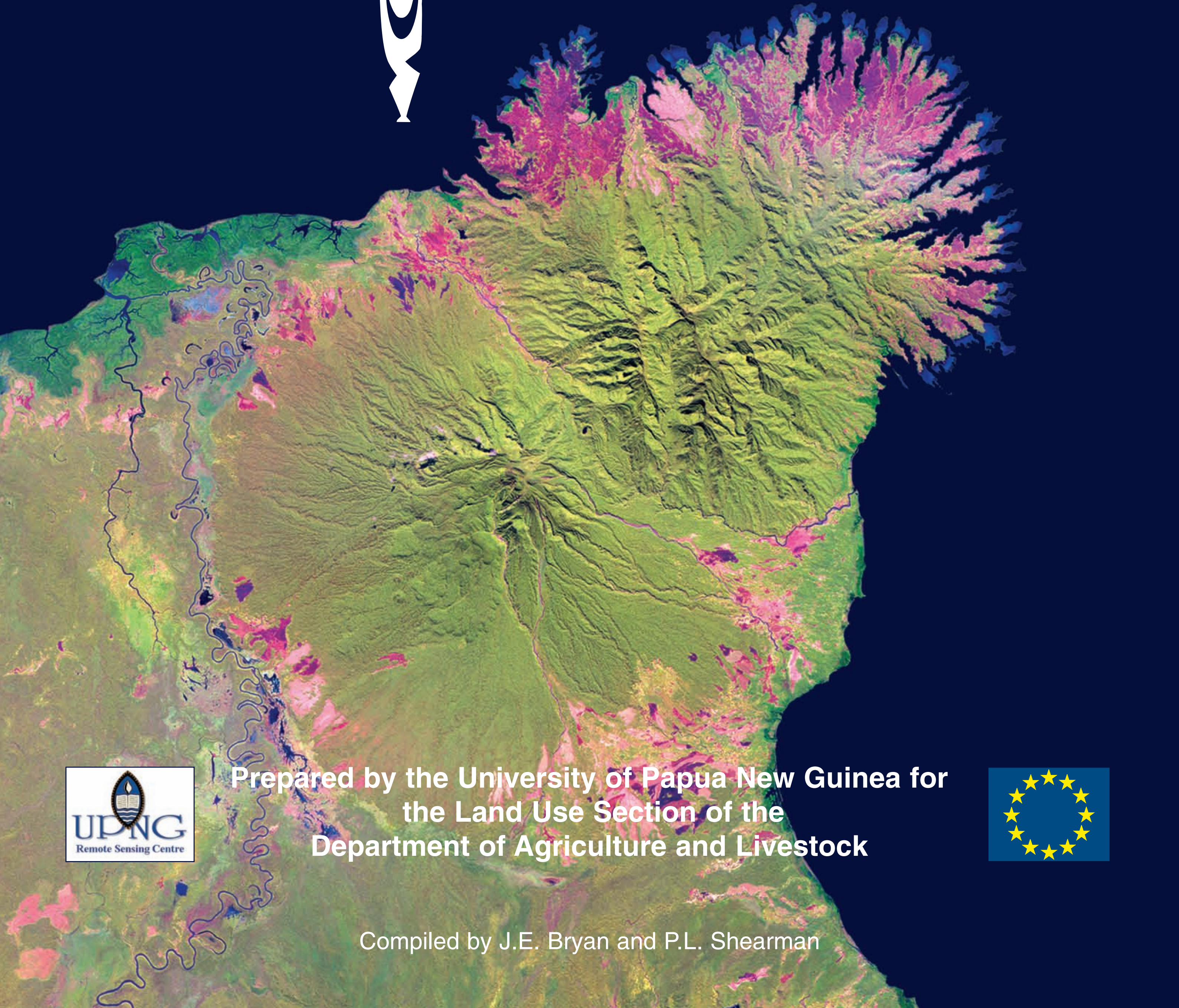
Papua New Guinea

PAPUA NEW GUINEA

RESOURCE INFORMATION SYSTEM HANDBOOK

3rd Edition

PNGRIS Publication No. 7



UPNG Remote Sensing Centre

Prepared by the University of Papua New Guinea for
the Land Use Section of the
Department of Agriculture and Livestock

Compiled by J.E. Bryan and P.L. Shearman

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Back cover: image of Kimbe region oil palm estates, West New Britain Province

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Foreword

John Hickey
Minister for Agriculture and Livestock

If one were to attempt to understand matters of economic importance to the majority of Papua New Guineans from the content of our newspapers or indeed from the majority of debates that occur in our Parliament, it would be relatively easy to conclude that we are a country of natural resource developers.

This is not the case. More than 86% of our people rely upon what they themselves can grow both for their food and supplementary income. We are still largely a nation of subsistence agriculturalists. In the past this fact has been poorly attended to in the formulation of GoPNG policy.

The commercial agricultural sector, engaged in the production of palm oil, rubber, sugar, copra, cocoa and other minor commodities creates approximately 20% of PNG's exports and is of great regional significance to the local economies of many areas in PNG. The Somare Government sees the expansion of this sector as central to the overall economic development of our nation. In the past 2 years we have committed substantial resources to the implementation of our National Agricultural Development Plan (NADP) which we hope will be a catalyst to increases the vibrancy and contributions of both the formal and informal sectors of the agricultural economy.

For these reasons I am pleased to see that the GoPNG is now able to use a revised PNG Resource Information System (PNGRIS) to assist in agricultural planning. While much of the work necessary to create PNGRIS was undertaken by numerous highly dedicated staff over the last 40 years, the revision of these data sets at a finer resolution will, I hope, allow the Department of Agriculture and Livestock to better serve the agricultural planning needs of the nation as a whole. This manual is the product of an outstanding collaboration between my Department's Land-Use Section and the University of Papua New Guinea - our premier university. It was made possible through the generous support of the European Union.

I look forward to seeing the manual in wide use in the near future in both the fields of agricultural research and land-use planning.

Sincerely,

John Hickey
Minister for Agriculture and Livestock
February, 2008.

Abstract

The Papua New Guinea Resource Information System (PNGRIS) is a geographic information system containing an inventory of natural resource and physical data as well as population parameters for Papua New Guinea (PNG). This handbook to the system explains the derivation, classification and presentation of the inventory information included in PNGRIS.

Acknowledgements

The Papua New Guinea Resource Information System (PNGRIS) is a computer-based natural resource and land-use planning tool. The third edition was produced by the University of Papua New Guinea Remote Sensing Centre for the PNG Government with the support of the European Union. The PNG Department of Agriculture and Livestock (DAL) Land Use Section houses and maintains the third edition of PNGRIS.

The handbook to the third edition of PNGRIS builds on the work in the first and second editions of PNGRIS. The first and second editions of PNGRIS, coordinated by John McAlpine and David Freyne, were prepared by a number of people including Jennifer Bellamy, Peter Bleeker, Jenny Chan, Susan Cuddy, Leanne Dobney, Robin Hide, Chandra Jayasuriya, Gael Keig, John Maguire, John Quigley, John Saunders and Elaine Spooner.

This third edition of the PNGRIS handbook was compiled and edited by Jane Bryan and Phil Shearman. A large team was involved in the preparation of the third edition including, Francis Daink, Mika Andrew, Stanley Oa, Michael Siri, Roger Suat, Sampson Wagia, Jimmy Mindipi, David Freyne and Graham Tyrie.

We also acknowledge support from the University of Papua New Guinea, particularly Lance Hill and Ross Hynes.

Abbreviations

DAL	**Department of Agriculture and Livestock**
EU	**European Union**
GIS	**Geographic Information System**
PNG	**Papua New Guinea**
PNGRIS	**Papua New Guinea Resource Information System**
RMU	**Resource Mapping Unit**

Preface

The first edition of this handbook for the Papua New Guinea Resource Information System (PNGRIS) was published in 1986 by the CSIRO Division of Water and Land Resources as the Natural Resource Series No. 6. PNGRIS is an inventory of natural resources, land-use and population information for the whole of Papua New Guinea (PNG). PNGRIS was established as a co-operative research project undertaken and jointly funded by the PNG Department of Primary Industry (DPI), now the Department of Agriculture and Livestock (DAL) and CSIRO. The project's objective was to determine both the current use and development potential of the nation's natural resources for food and cash crop production, taking into account population growth and distribution.

Much of the information in the first two versions of PNGRIS was derived from a prior long-term (1952-72) natural resource survey programme. Before work commenced on the development of PNGRIS in 1980, CSIRO, the Geological Survey of PNG and the Australian Bureau of Mineral Resources had undertaken numerous surveys resulting in a comprehensive series of maps, books and supporting publications on each of the major natural resources of the country.

The first version of PNGRIS integrated this comprehensive body of information on natural resources and their use into a computer information system to facilitate data storage, retrieval and analysis. This work occurred between 1981-86, was funded by DPI and CSIRO, and resulted in the installation of the system in DPI. The first edition of this handbook was produced at that time.

Developments in microcomputer technology in the late 1980's and 1990's enabled the addition of a computer mapping system in PNGRIS to replace the previous manually produced maps. This led to a digital upgrade of PNGRIS between 1992 and 1995 that contained additional data. The second edition of the PNGRIS handbook describes this version of PNGRIS.

The first two versions of PNGRIS consisted of a computerized map dividing PNG into 4837 land units, called Resource Mapping Units (RMUs). Each RMU delineated a relatively homogenous region in terms of geology, topography and climate at a 1:500,000 scale. Attached to each resource mapping unit was a database containing a summarized list of landform type, physical data, land-use information and population figures.

In the years since the development and later upgrading of PNGRIS, advancements in Geographic Information Systems (GIS) and the availability of relatively inexpensive satellite-derived data have meant that many of the landscape features summarized at a 1:500,000 scale in the first two versions of PNGRIS can now be compiled at a much more detailed scale.

The purpose of the 2007 PNGRIS upgrade was to produce a modern Geographic Information System containing where available, more detailed datasets for each land feature, than those contained in the previous 1:500,000 version of PNGRIS. The outcome of this work is described in this third edition of the PNGRIS handbook.

The digital GIS datasets of this PNGRIS update can be obtained from:

The Land-Use Section,
Science and Technology Branch,
Department of Agriculture and Livestock,
P.O. Box 1863, Boroko, NCD,
Papua New Guinea.

Tel: (675) 321 4458/320 2959
Fax: (675) 321 1046
Email: pngris@daltron.com.pg

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2007 PNGRIS upgrade

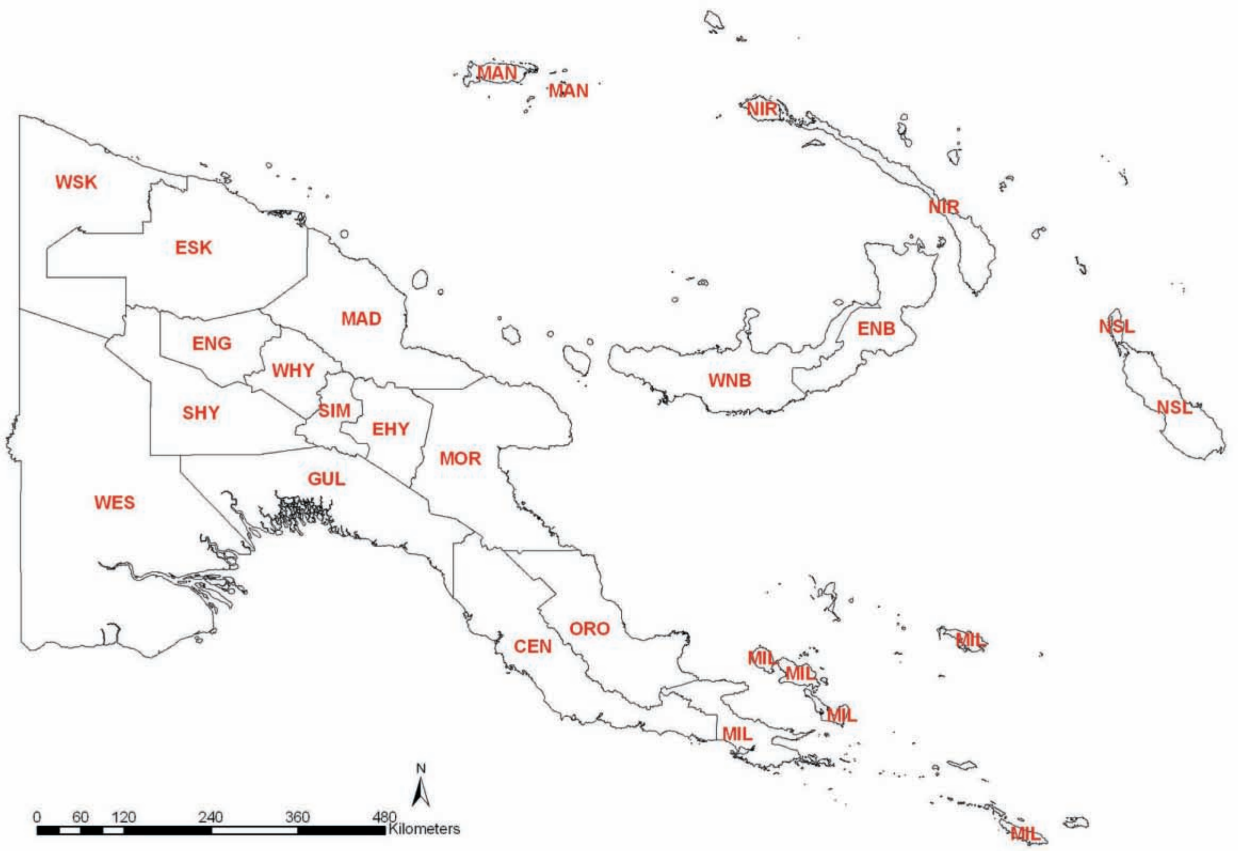
The upgraded Papua New Guinea Resource Information System (PNGRIS) is a geographic information system (GIS) consisting of a series of computerized maps for use in the MapInfo GIS software package. The computerized maps, or layers, show various features of the landscape and environment that are useful for natural resource use planning, development and conservation. Each computerized map layer has a table or database attached to it giving a description of each feature in the map. The information contained in the database is designed to be viewed and analyzed interactively inside MapInfo software, but is also compatible with standard database software such as Microsoft Access. This means that the information about natural resources in PNG is readily compatible with other pre-existing databases in standard formats.

There are six broad categories of maps included as part of the PNGRIS GIS: topographic map layers, climatic map layers, geologic map layers, a population layer, a soils layer, and an inundation layer. A full list of the map layers contained in the PNGRIS upgrade is presented in Table 1.

Table 1: GIS layers included in the PNGRIS upgrade

Category	PNGRIS Layer	Source	Agency/ Project	Scale
Topography	Elevation/altitude	90m SRTM digital elevation model	UPNG	1:250,000
	Topographic position	90m SRTM digital elevation model and FLAG model	UPNG, 2005 Summerell	1:250,000
	Slope	90m SRTM digital elevation model	UPNG	1:250,000
	Aspect	90m SRTM digital elevation model	UPNG	1:250,000
	Landform	PNGRIS version 2	PNGRIS	1:500,000
Climate	Mean annual rainfall	PNG weather station rainfall information interpolated using 1km SRTM digital elevation model	Worldclim	1:250,000
	Rainfall seasonality	Worldclim monthly grids classified according to rainfall seasonality as defined by Fitzpatrick et. al (1966)	Worldclim	1:250,000
	Mean annual maximum temperature	PNG weather station data interpolated across PNG using 1km SRTM digital elevation model	Worldclim	1:250,000
	Mean annual minimum temperature	PNG weather station data interpolated across PNG using 1km SRTM digital elevation model	Worldclim	1:250,000
	Mean annual solar radiation	PNG weather station solar radiation data interpolated across PNG using 1km digital elevation model	BioRap	1:250,000
Geology	Geology	Digitized 1:250,000 Geoscience Australia map sheets	Biorap	1:250,000
	Rock type	Digitized 1:250,000 Geoscience Australia map sheets. Reclassified according to the PNGRIS version 1 rock type classes	Biorap	1:250,000
Soil	Soil	PNGRIS version 1 soil data, Topographic position maps	DAL, PNGRIS, UPNG	1:250,000
Population	Population	2000 Census data	PNG National Mapping Bureau	1:250,000
Inundation	Inundation	PNGRIS version 1, UPNG slope, topographic position maps	PNGRIS,	1:250,000

The map layers contained in the PNGRIS upgrade are stored on a Provincial basis. Each of the 19 Provinces (the National Capital District is included as part of Central Province) has a separate map layer for each of the attributes listed in Table 1. Each of the 19 provinces in PNG is shown in Figure 1.



CEN	–	**Central**	**MAN**	–	**Manus**	**SHY**	–	**Southern Highlands**
EHY	–	**Eastern Highlands**	**MIL**	–	**Milne Bay**	**WES**	–	**Western**
ENB	–	**East New Britain**	**MOR**	–	**Morobe**	**WHY**	–	**Western Highlands**
ENG	–	**Enga**	**NIR**	–	**New Ireland**	**WNB**	–	**West New Britain**
ESK	–	**East Sepik**	**NSL**	–	**North Solomons**	**WSK**	–	**West Sepik**
GUL	–	**Gulf**	**ORO**	–	**Oro**			
MAD	–	**Madang**	**SIM**	–	**Simbu**			

Figure 1: Provincial boundaries.

Several datasets, such as the topographic position map and the soil map described in sections 2.3 and 5 respectively, were created at the scale and in the manner described in this document primarily to be used in the Papua New Guinea Land Evaluation System (PNGLES). PNGLES is the version of the Automated Land Evaluation System (ALES) designed for Papua New Guinea (Venema & Daink, 1992; Rossiter & Wambeke, 2000). It is a system designed to produce suitability assessments of the land for particular land-uses. PNGLES is used by the Department of Agriculture and Livestock (DAL) Land-Use Section to produce maps of potential crop suitability in PNG. The method for using the upgraded PNGRIS layers in PNGLES is outlined in Appendix 1. Several examples of the resultant crop suitability maps are also presented in Appendix 1 to illustrate the utility of the upgraded PNGRIS GIS.

1 Introduction

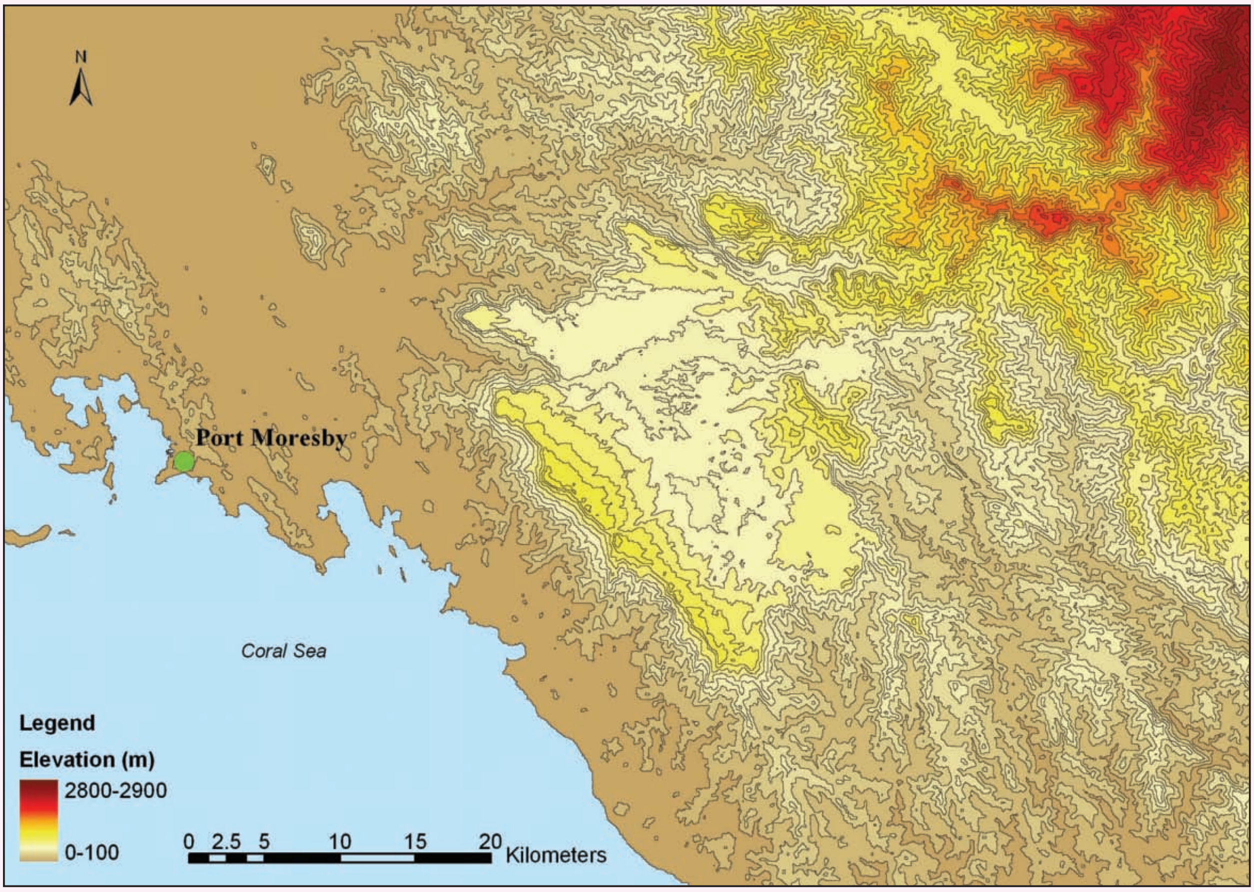
The following parts of this document present the background to the creation of PNGRIS, followed by a discussion on how each map layer in PNGRIS was created, the data used to create it, and the scale and limitations of the map layer.

1.1 Background

Previous versions of PNGRIS consisted of a single map which divided PNG into 4,837 regions or mapping units (Resource Mapping Units or RMUs) connected to a database containing information about the landscape represented by each RMU. The database attached to each RMU described that particular land unit in terms of climate, topography, vegetation/land-use, population and rock type. Each RMU in the previous version of PNGRIS was defined as an area of relatively homogenous geology, climate and topography at a scale of 1:500,000 (Bellamy & McAlpine, 1995). The transition from an RMU-based system to a GIS containing a separate map layer for each attribute was undertaken due to a number of limitations associated with the RMU approach, and also as a result of newer, more detailed information becoming available.

There are several limitations in viewing the landscape as a series of RMU's. Firstly, despite being defined as homogenous in terms of geology, climate and topography at a scale of 1:500,000, there is considerable variation locally which is not captured at such a broad scale. This was acknowledged in the previous version of PNGRIS and was addressed by listing the dominant classes of each landscape feature in any given RMU. For example, up to three different dominant soil types, up to three different dominant vegetation types and two different rock types are listed in each RMU in the previous version of PNGRIS. The major difficulty with listing different dominant types that exist within a mapping unit is that the boundary between the different attribute types is not known. This is a problem for many land-use evaluation questions. For example, if the dominant slope in an RMU is 20-30 degrees, and the subdominant slope is 5-10 degrees, and one of the subdominant soils is highly fertile, but the dominant soil is not, it is not known if the fertile soil occurs on the steep or on the gentle slope. Many forms of land-use may be appropriate in places where the fertile soil is occurring on the gentle slopes, but not where it occurs on steeper slopes. Similarly, if the fertile soil occurs on gentle slopes bounded by areas of steep slopes, the costs of transport from the fertile region across the steep slopes may not be viable. Without the boundaries of each attribute, in this example soil and slope, such analyses cannot be made. Many areas of land will be viewed as suitable for some activities that may be inappropriate, and many land-use activities that may be possible in an RMU will be dismissed as unsuitable.

As a result of the availability of satellite imagery showing highly detailed information about the earth's surface, as well as the progress of GIS technology in the 20 years since PNGRIS was first created, it is now possible to overcome some of the limitations described above for many of the attributes contained in the old PNGRIS. To overcome difficulties of scale and of not knowing where the boundaries for each attribute lie within each RMU, PNGRIS was upgraded to a conventional geographic information system (GIS). This meant that each attribute in the old version of PNGRIS was produced as a map layer in its own right, with the boundary for each attribute retained rather than being aggregated to a coarse scale mapping unit. The most detailed information available was used to produce each map layer, so that the scale for most map layers in the upgrade is much finer than in the previous version of PNGRIS. In future, analyses that use the updated PNGRIS data will no longer be limited to a coarse scale of 1:500,000. However, where there was no finer scale information available, the RMU based layer from the older version of PNGRIS was included in the upgrade. An example of the RMU based PNGRIS and the upgraded system is shown in Figure 2.



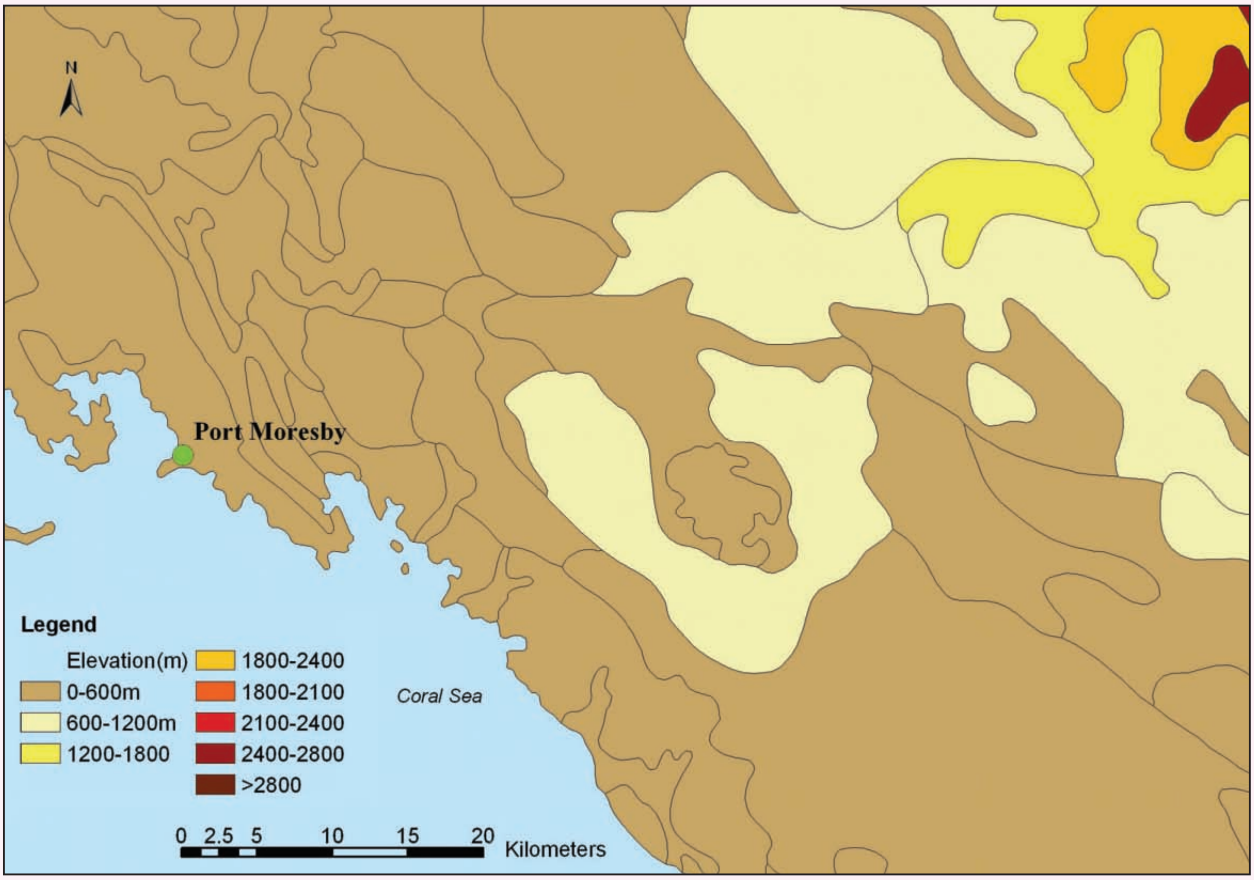


Figure 2: An example of the upgraded PNGRIS compared to the previous RMU based system. The upper image shows the elevation/altitude map layer included in the 2007 PNGRIS upgrade, the lower image shows the elevation/altitude map contained in the previous RMU-based version of PNGRIS. Significantly more detail can be seen in the upgraded version.

1.2 Datasets contained in PNGRIS

There are six broad groups of GIS layers contained in the PNGRIS upgrade; climate, geology, topography, population, soil and inundation. For many of these attributes the data was originally constructed in the ESRI ArcInfo GIS system as a continuous ESRI grid before being converted to a classified vector layer for use in the MapInfo software system. The final PNGRIS GIS data are in MapInfo vector format.

Each MapInfo vector layer has a table attached to it which contains a code describing the landscape feature represented by each polygon, a description of what the code represents, and the area in square kilometres of each polygon.

As shown in Table 1, the map layers contained in the upgraded PNGRIS were created from a variety of different sources at a variety of different scales, and as a result, differed in their coastlines. Each map layer was therefore fitted to the coastline produced by the UPNG Remote Sensing Centre. This coastline was derived from orthorectified Landsat ETM+ imagery.

As much detail as possible was retained in each of the map layers described in this document. For many purposes, such a high level of detail may not be necessary and in such cases the PNGRIS layers can be readily reclassified to show less detail, which also results in a smaller file size. The method of combining classes to produce a less detailed map layer with a smaller file size in MapInfo is presented in Appendix 1 section 8.3.

All datasets are in the Geographics projection which uses latitude and longitude as map coordinates and the Australian Geodetic Datum 1984 (AGD84).

A description of each topographic, climatic, geologic, population, soil and inundation map layer produced for the PNGRIS upgrade is presented in the following pages, along with a description of the data used to generate the map, and the limitations of the dataset.

2 Topographic map layers

2.1 Introduction

Topographic attributes included in the PNGRIS upgrade are elevation (altitude), slope, aspect, landform and topographic position. These attributes are used to describe the topography of the landscape in PNG. Elevation, slope, aspect, landform and topographic position not only describe the landscape, but also have a strong influence on both the rate and type of geomorphic processes that are in operation, as well as the capability of the land for certain uses.

2.2 Elevation (altitude)

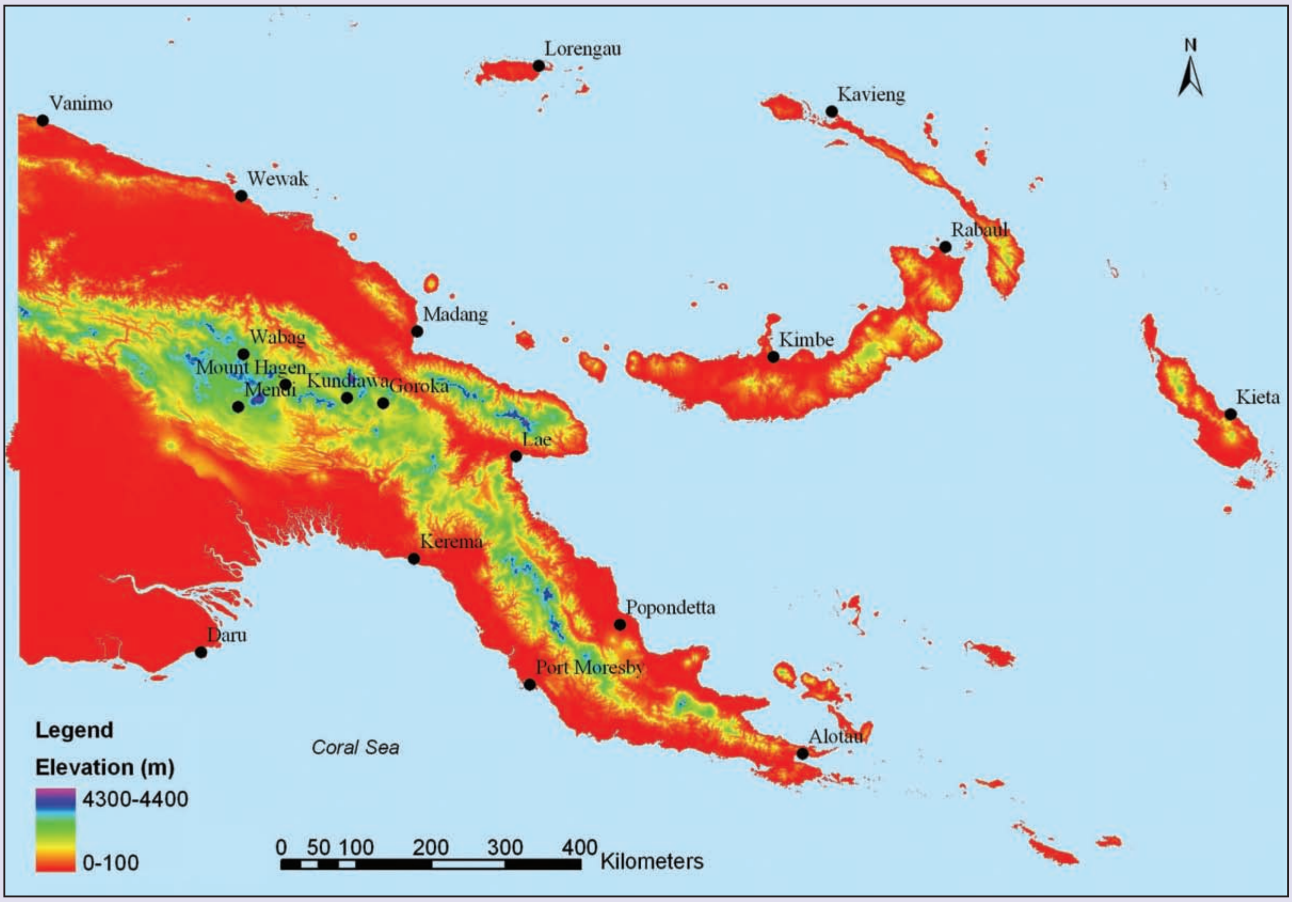
2.2.1 Classification

The map of elevation contained in the upgraded PNGRIS shows the height of the landscape measured in metres above sea level. The elevation layer contains one class per 100m increase in elevation. At altitudes greater than 500m, elevation can also be used as a surrogate for temperature, as outlined in section 3.4. Each of the elevation classes in the upgraded PNGRIS is listed in Table 2. The PNGRIS map of elevation is shown in Figure 3.

Table 2: Elevation classes for PNG

Code	Elevation/Altitude class (metres)
1	0 – 100
2	100 – 200
3	200 – 300
4	300 – 400
5	400 – 500
6	500 – 600
7	600 – 700
8	700 – 800
9	800 – 900
10	900 – 1000
11	1000 – 1100
12	1100 – 1200
13	1200 – 1300
14	1300 – 1400
15	1400 – 1500
16	1500 – 1600
17	1600 – 1700
18	1700 – 1800
19	1800 – 1900
20	1900 – 2000
21	2000 – 2100
22	2100 – 2200

Code	Elevation/Altitude class (metres)
23	2200 – 2300
24	2300 – 2400
25	2400 – 2500
26	2500 – 2600
27	2600 – 2700
28	2700 – 2800
29	2800 – 2900
30	2900 – 3000
31	3000 – 3100
32	3100 – 3200
33	3200 – 3300
34	3300 – 3400
35	3400 – 3500
36	3500 – 3600
37	3600 – 3700
38	3700 – 3800
39	3800 – 3900
40	3900 – 4000
41	4000 – 4100
42	4100 – 4200
43	4200 – 4300
44	4300 – 4400



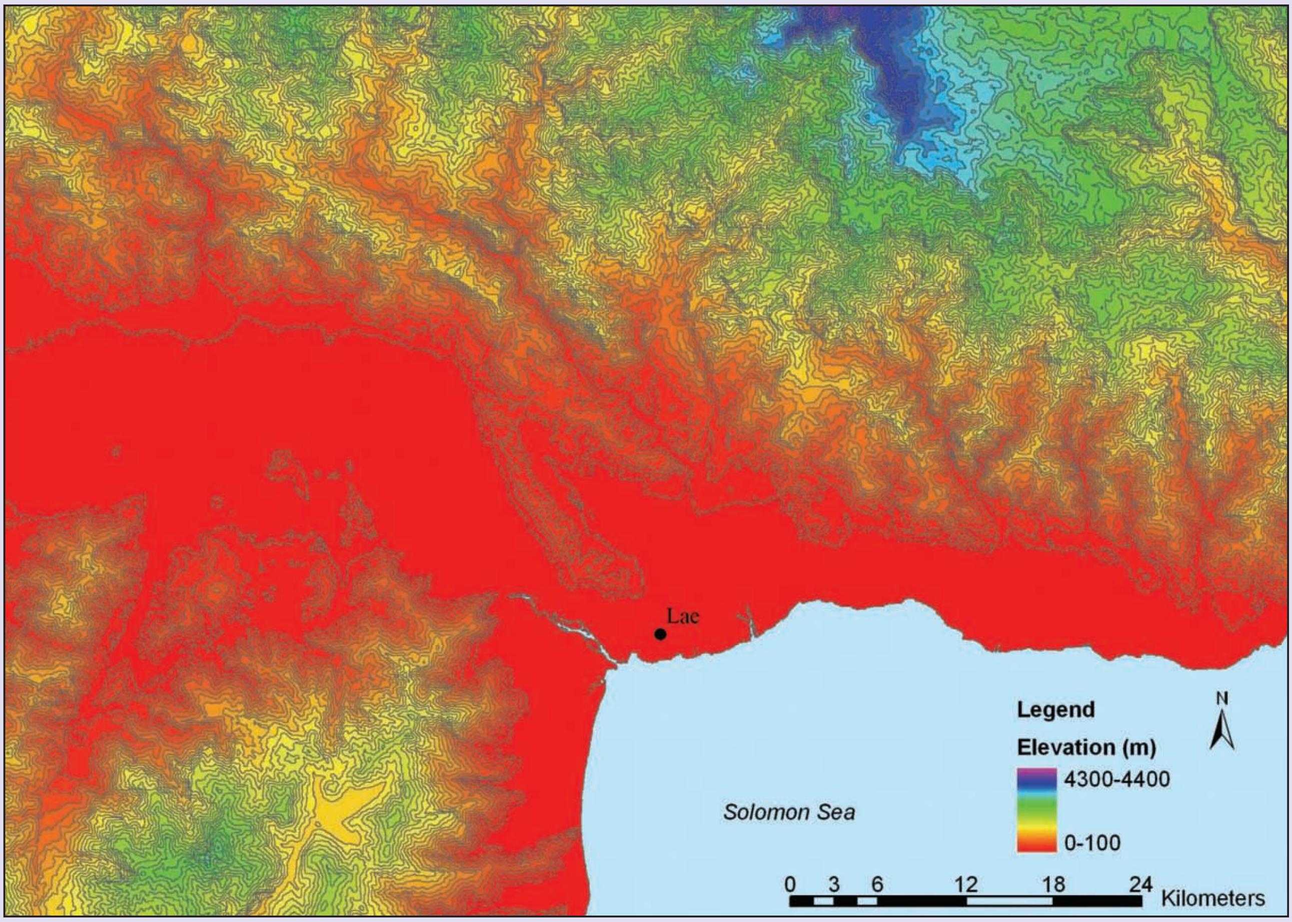


Figure 3: Upgraded PNGRIS elevation layer showing one class per 100m increase in altitude. The upper image shows the upgraded elevation map for the entire country. The lower image shows a close-up view of the upgraded elevation map in the Lae area in Morobe Province.

2.2.2 Data sources

The elevation layer was created from the University of Papua New Guinea Remote Sensing Centre's digital elevation model (DEM). The UPNG DEM is a computerized grid representing the altitude of PNG. Each grid cell in the DEM contains a measurement of the average height above sea level, referred to as elevation or altitude, at that particular location. Each grid cell is 90 by 90m in size.

The DEM was initially created using NASA Shuttle Radar Topography Mission (SRTM) data. However, the DEM produced from the SRTM data contained missing values for many areas in PNG, especially in steep valleys where there were difficulties with the radar signal being reflected back to the shuttle. To overcome this problem, the UPNG Remote Sensing Centre replaced missing values with elevations obtained from 1:250,000 map sheets, surveyed spot heights and other available information. The resultant DEM was then used to produce the PNGRIS elevation map.

2.2.3 Method

The PNGRIS elevation layer was created by reclassifying the UPNG DEM using the ESRI ArcInfo GIS. Elevation classes spanning 100m intervals were chosen. The selection of 100m intervals was a compromise between keeping as much detail as possible in the dataset and having a GIS layer with a manageable file size. The resultant classified ESRI grid was then converted into MapInfo vector format.

2.2.4 Limitations

The elevation layer was created from a DEM with a 90m resolution. Rapid changes in elevation and topographically complex features as well as local small scale variation in elevation are therefore not captured in the elevation layer.

2.3 Topographic position map

2.3.1 General discussion

This layer is a map of estimated topographic position in Papua New Guinea. The topographic position layer shows PNG divided into ridge tops/upper slopes, mid slopes, lower slopes and valleys. This layer was not present in the previous version of PNGRIS.

A topographic position map was created for PNG primarily to aid in the production of a soil map, which is a key component of agricultural planning. The previous version of PNGRIS listed three soil types within each RMU. As a result of more detailed topographic information now being available, from the 90m DEM (see section 2.2), it was possible to allocate each of the soils listed in the previous version of PNGRIS to a location in the landscape using this detailed topographic data. This is further discussed in section 5.

2.3.2 Data sources

The GIS map of topographic position used in the new version of PNGRIS was created from the UPNG DEM described in section 2.2.2, and from the slope map derived from this DEM, as discussed in section 2.4.

2.3.3 Method

The topographic position map was produced using the ‘upness index’ derived from the UPNG DEM (see section 2.2). The upness index is part of the Fuzzy Landscape Analysis Geographic Information System (FLAG) model (Roberts et al, 1997; Summerell et al, 2005). The upness index measures the number of grid cells in a digital elevation model in a particular catchment and surrounds that are either at a higher elevation (uphill) from a particular grid cell, or at the same elevation of that grid cell. When all the grid cells representing a catchment are viewed together, those cells within the catchment and surrounding area which have the fewest cells uphill from them can be seen as local high points in the landscape, or ridge tops. Those grid cells with the highest number of cells either uphill from them or at the same elevation are local low points in the landscape, that is, valleys or low-lying flat areas.

The digital elevation model used to calculate upness and therefore topographic position was very large. Memory and computer processor limitations meant that the DEM had to be split so that the upness index was created for several regions on a catchment basis, rather than as one index. A limitation of this method of estimating topographic position is that different areas may be assigned a different topographic position depending on the size of the DEM used to calculate upness. Several different sized DEMs were used to assess the effects of DEM size on topographic position. It was judged that the larger the DEM, the more consistent were the results. Therefore the largest sized regions that computer processor and memory limitations would allow were used to create the upness index for PNG.

The FLAG model method of dividing the continuous upness index into topographic position classes is fully described by Summerell et al (2005). Briefly, changes in the concavity of the distribution of the upness index are used to define breaks between ‘upper slope’, ‘mid slope’, ‘lower slope’, and ‘valley bottom’. Field checking of the topographic position map produced from this classification was undertaken by DAL Land-Use Section, a consulting soil expert and the UPNG Remote Sensing Centre in the Sogeri and Tubusereia region, Central Province, and around Alotau in Milne Bay Province. It was found that some areas were being allocated to the ‘valley bottom’ classes which, although low-lying in the context of the surrounding landscape, contained considerable variation in slope. The ‘valley bottom’ class was therefore further subdivided according to slope. Areas in the landscape being allocated ‘valley bottom’ which had a slope greater than 2 degrees were allocated the class ‘lower slope 2’. Areas in the landscape allocated the class ‘valley bottom’ which had a slope 0-2 degrees were re-assigned to the class ‘valley bottom undulating’, and areas allocated the class ‘valley bottom’ with a slope of 0 degrees were given the label ‘valley bottom flat’.

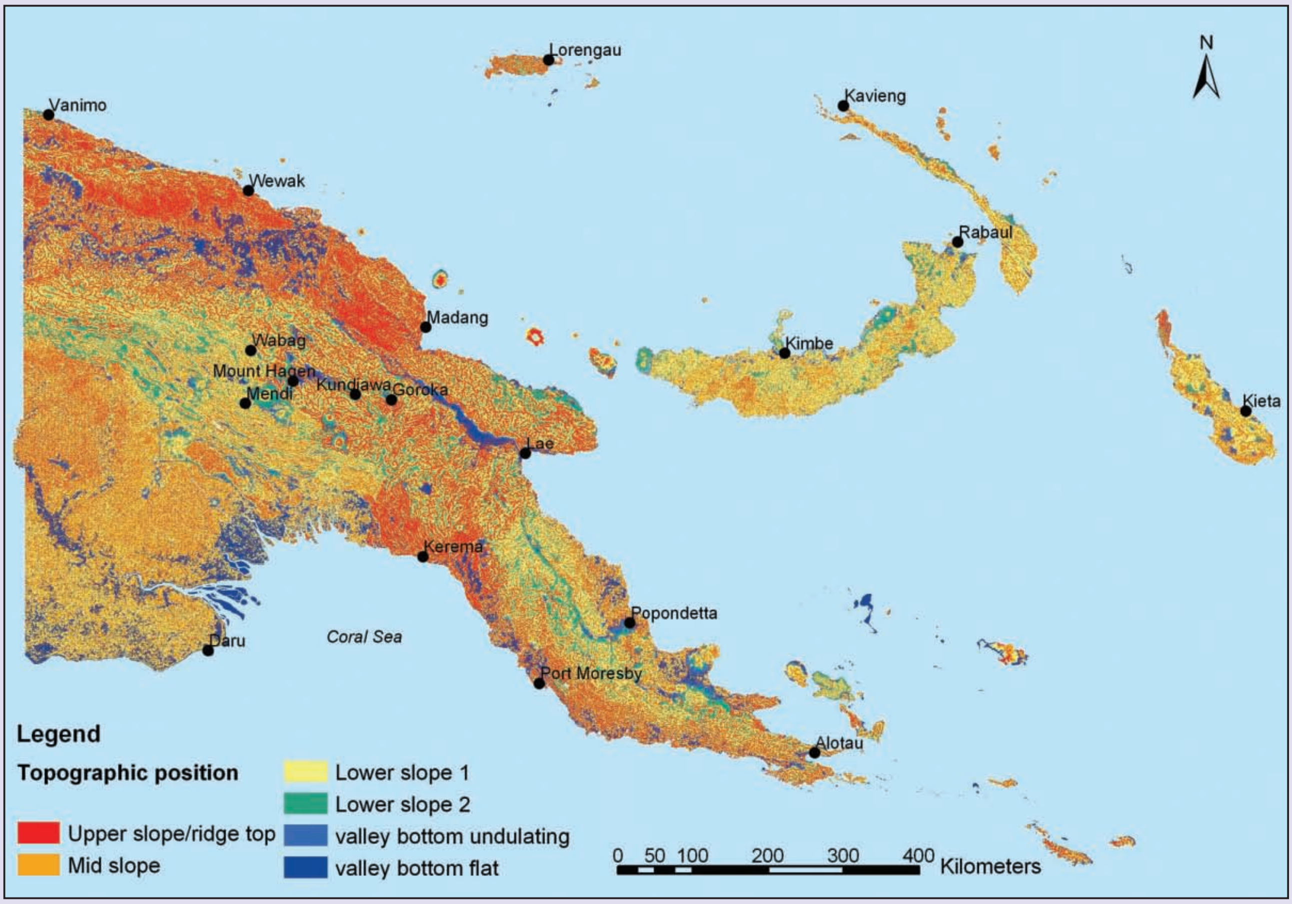
The primary reason for further dividing topographic position in this fashion was to assist the allocation of a soil type to a particular topographic position to enable the production of a more detailed soil map (see section 5.4).

2.3.4 Classification

The final topographic position classification used in the PNGRIS upgrade is outlined in Table 3. While it would have been desirable to separate ridge tops from upper slopes, time and dataset limitations prevented this from being a feasible option. The topographic position map for PNG is shown in Figure 4.

Table 3: Topographic position classification

Code	Topographic position	Description
1	Valley bottom flat	Local low area in the landscape, flat (slope = 0 degrees)
2	Valley bottom	Local low area in the landscape, undulating undulating slope >0 and <2 degrees
3	Lower slope 2	Local low area in the landscape, slopes >2 degrees
4	Lower slope 1	Lower slope
5	Mid slope	Mid slope
6	Upper slope/ridge top	Local highest area in the landscape



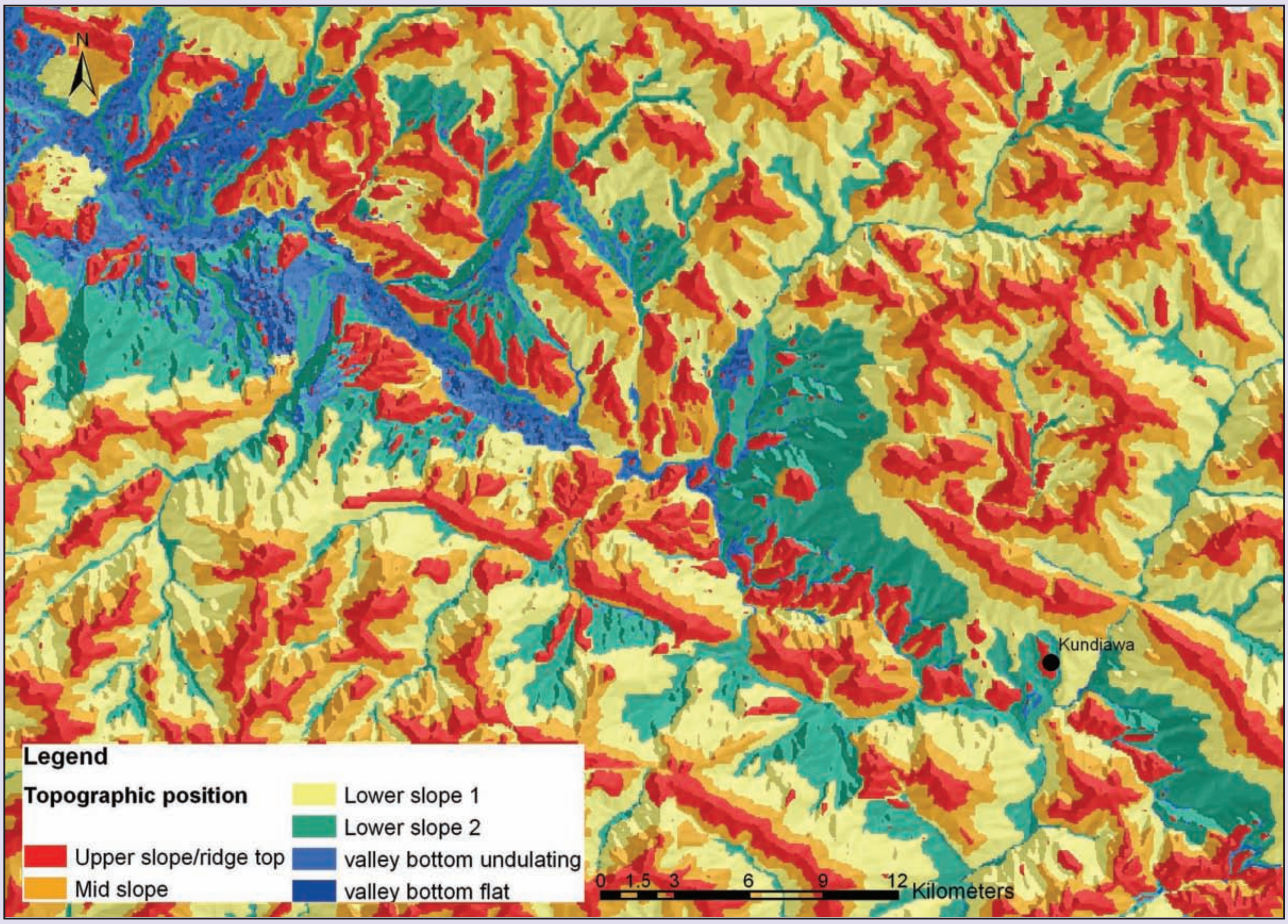


Figure 4: Topographic position maps. The upper image shows the topographic position map for the entire country. The lower map shows a close-up view near Kundiawa in Simbu Province.

2.3.5 Limitations

The topographic position map was created at a higher level of detail than was the field data assigned to each position in the landscape.

The topographic position map highlights relative relief. This is illustrated in Figure 5. For this reason, it is recommended that the topographic position map be used in conjunction with the landform map described in section 2.6 to aid interpretation of the topographic features.

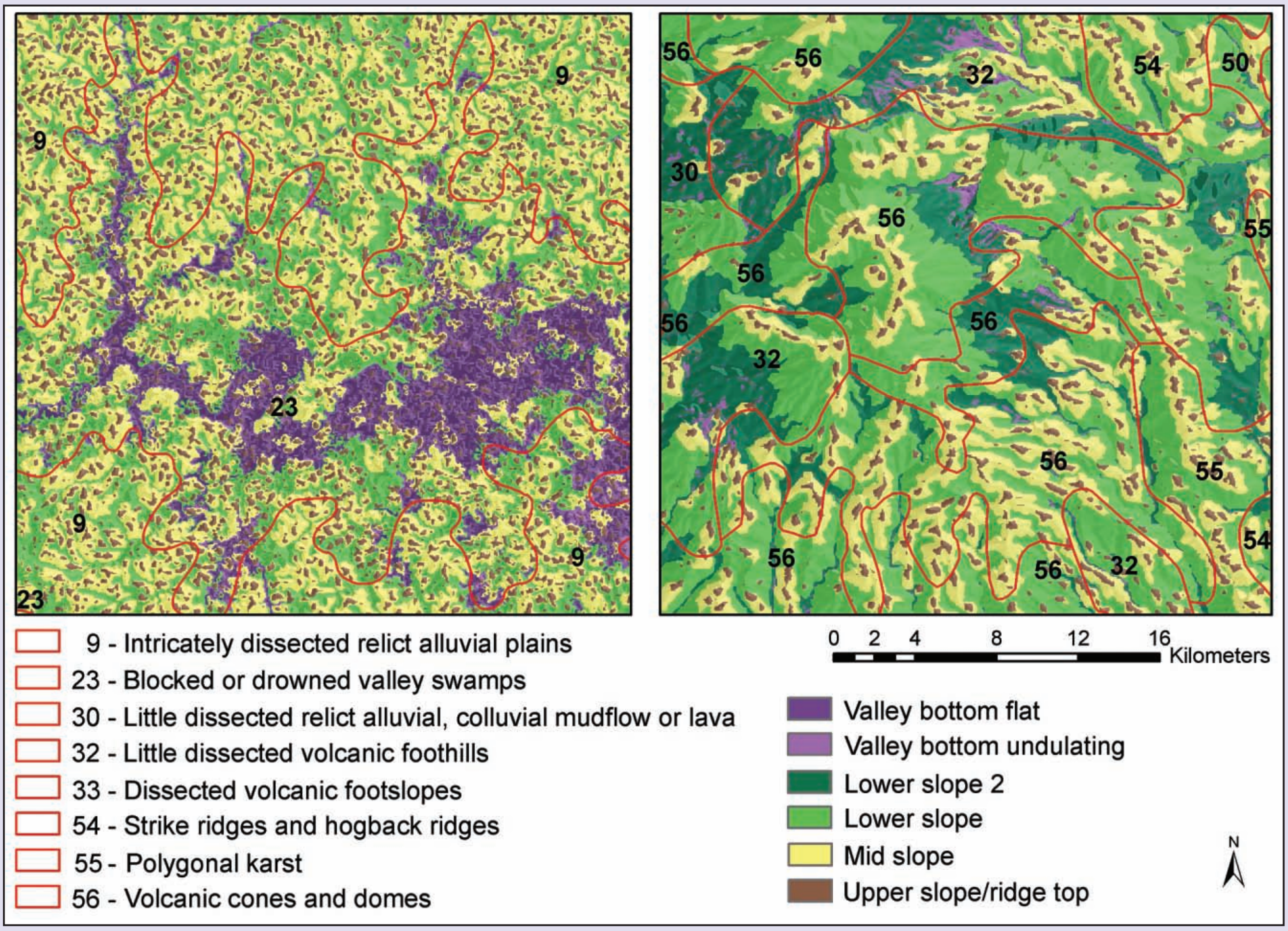


Figure 5:. Topographic position map showing the relatively flat plains in Western Province on the left and steep terrain in Southern Highlands Province on the right. The landform map is shown in red. In Western province, the 'valley bottom' classes shown in purple is occur in landform 23 or 'Blocked valley or drowned valley swamp' and can be interpreted as the valley swamp. The brown 'upper slope/ridge tops' are local high points in the surrounding swamp. In Southern Highlands however, the brown 'upper slope/ridge tops' occurring in landform type 56 or 'Volcanic cones and domes' refer to the peaks of the volcanic cones or domes, and the purple 'valley bottoms' and dark green 'Lower slope 2' are the depressions or flattenings at the foot of the dome.

Different areas of the landscape were allocated different topographic positions depending on the size of the DEM used to calculate the upness index and hence the topographic position map. Although it was found that the larger the size of the DEM (catchment) used to produce the map the more stable the results, there still remain some differences in the topographic position map at the boundary between each DEM segment used to make the map. This problem highlights the subjectivity, and dependence on the scale at which one views the landscape when classifying an area into topographic position. As illustrated in Figure 6, the size of the surrounding area as well as the scale at which the landscape is viewed will have a direct impact on where the boundaries between topographic positions are defined.

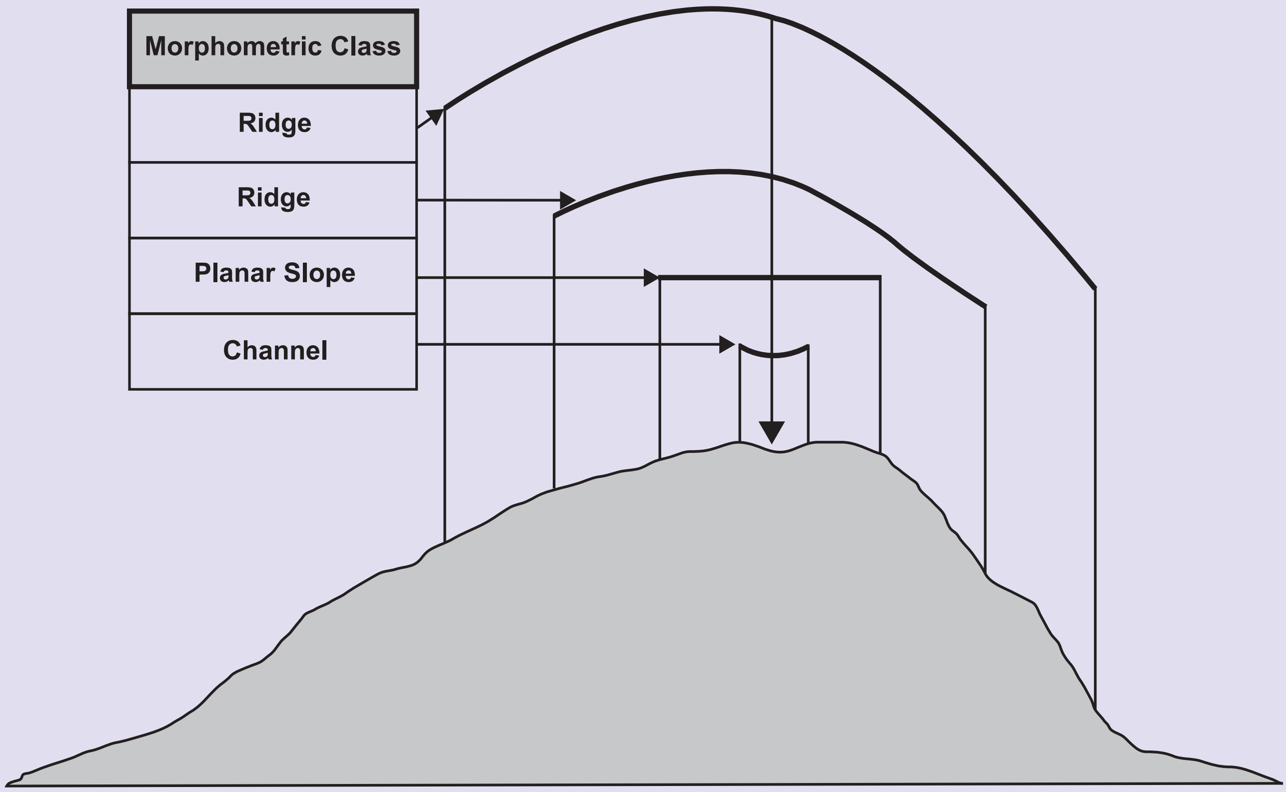


Figure 6: Topographic position (morphometric class) varies with the scale at which it is measured and also depends on the surrounding landscape. From: Fisher, Wood & Cheng (2003).

2.4 Slope

2.4.1 General discussion

Slope is defined as the rate of change of elevation. It was created from the UPNG digital elevation model described in section 2.2.2. Slope is measured in degrees from the horizontal plane. A completely flat surface will yield a slope measurement of 0 degrees and a vertical cliff face will yield a slope value of 90 degrees.

2.4.2 Classification

There are 10 classes of slope included in the upgraded PNGRIS slope map. Initially these classes were defined based upon Olofin's (1974) description of slope. This was also the system used in previous versions of PNGRIS. In the upgraded version of PNGRIS, this classification system was refined to separate 0 degree slopes from 0-2 degree slopes and also to further separate the 10-20, 20-30 and >30 categories. The classification system adopted for slope is outlined in Table 4 and the slope map of PNG is shown in Figure 7.

Table 4: Slope classification used in the PNGRIS upgrade

Code	Slope (degrees)
1	0
2	0 – 2
3	2 – 5
4	5 – 10
5	10 – 15
6	15 – 20
7	20 – 25
8	25 – 30
9	30 – 35
10	>35

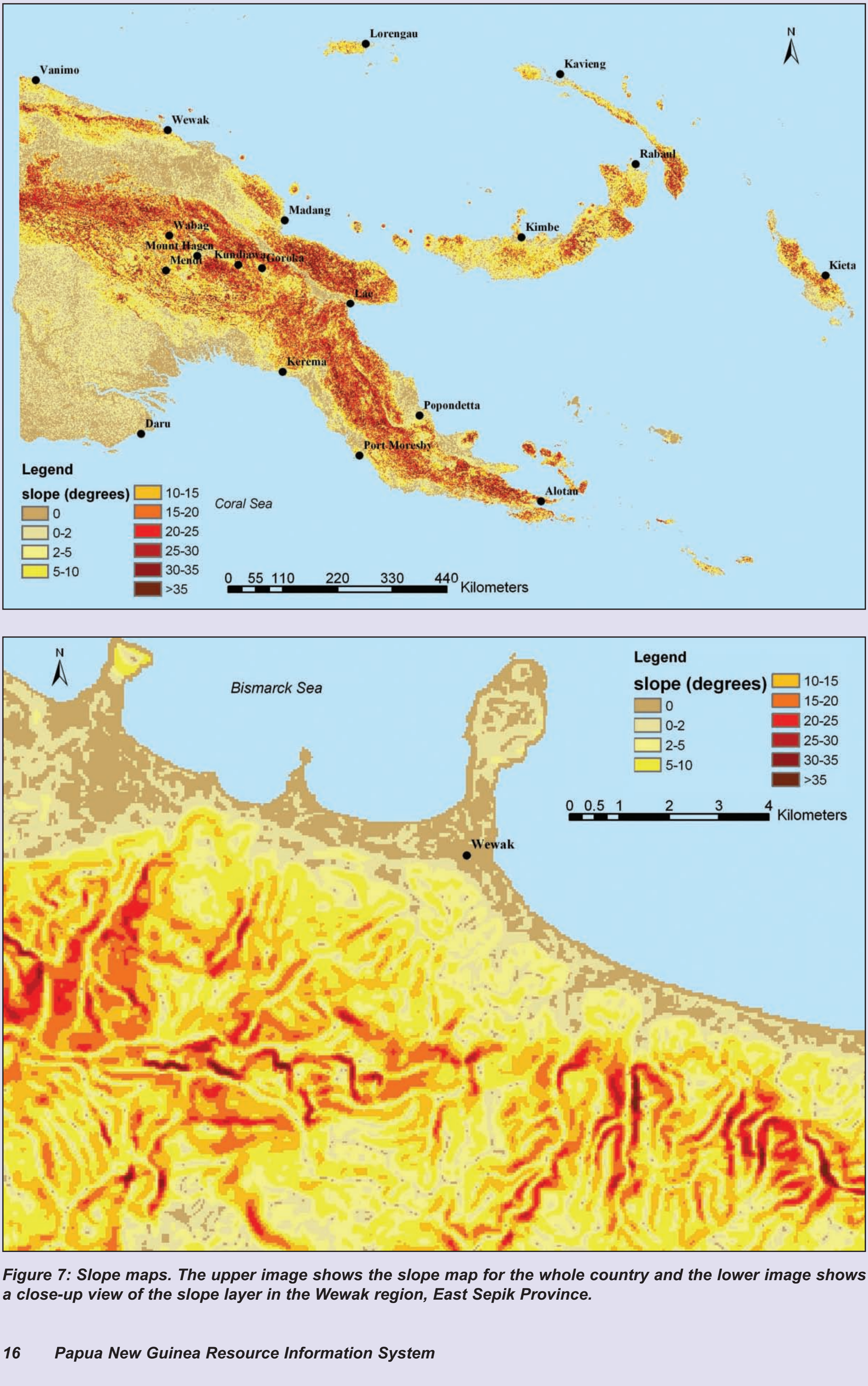


Figure 7: Slope maps. The upper image shows the slope map for the whole country and the lower image shows a close-up view of the slope layer in the Wewak region, East Sepik Province.

2.4.3 Data sources

The slope layer was created from the UPNG's 90m DEM described in section 2.2.2. A steep slope has a rapid change in elevation and a gentle slope has a gradual change in elevation.

2.4.4 Method

The 'slope' command in the ESRI ArcInfo GIS was used to calculate slope from the DEM. This raster layer was then classified into 10 classes and converted to MapInfo vector format.

2.4.5 Limitations

The DEM measures average elevation in a 90m square or grid cell and slope measures the rate of change in elevation between adjacent 90m squares. Rapid changes in elevation or steep slopes occurring within a 90m square will therefore be smoothed by the averaging process which produced the DEM. This means that steep slopes occurring within a 90m area will not be apparent in the slope map.

2.5 Aspect

2.5.1 General discussion

Aspect refers to the direction that a hill slope faces. Aspect is associated with the effects of wind, sun, soil wetness, and different aspects can relate to different vegetation types. It can therefore be useful from the perspective of agricultural planning.

2.5.2 Classification

Standard compass directions were used as the classification system for aspect. Within this classification scheme, nine aspect classes were included in the upgraded PNGRIS: North, north-east, east, south-east, south, south-west, west, and north-west facing slopes, as well as flat land. These classes and their definition in terms of degrees from north are listed in Table 5. The aspect map for PNG is shown in Figure 8.

Table 5: Aspect classification used in the PNGRIS upgrade

Code	Aspect (direction)	Aspect (degrees from north)
1	North	337.5 – 360, 0 – 22.5
2	North-east	22.5 – 67.5
3	East	67.5 – 112.5
4	South-east	112.5 – 157.5
5	South	157.5 – 202.5
6	South-west	202.5 – 247.5
7	West	247.5 – 292.5
8	North-west	292.5 – 337.5
9	Flat	Flat

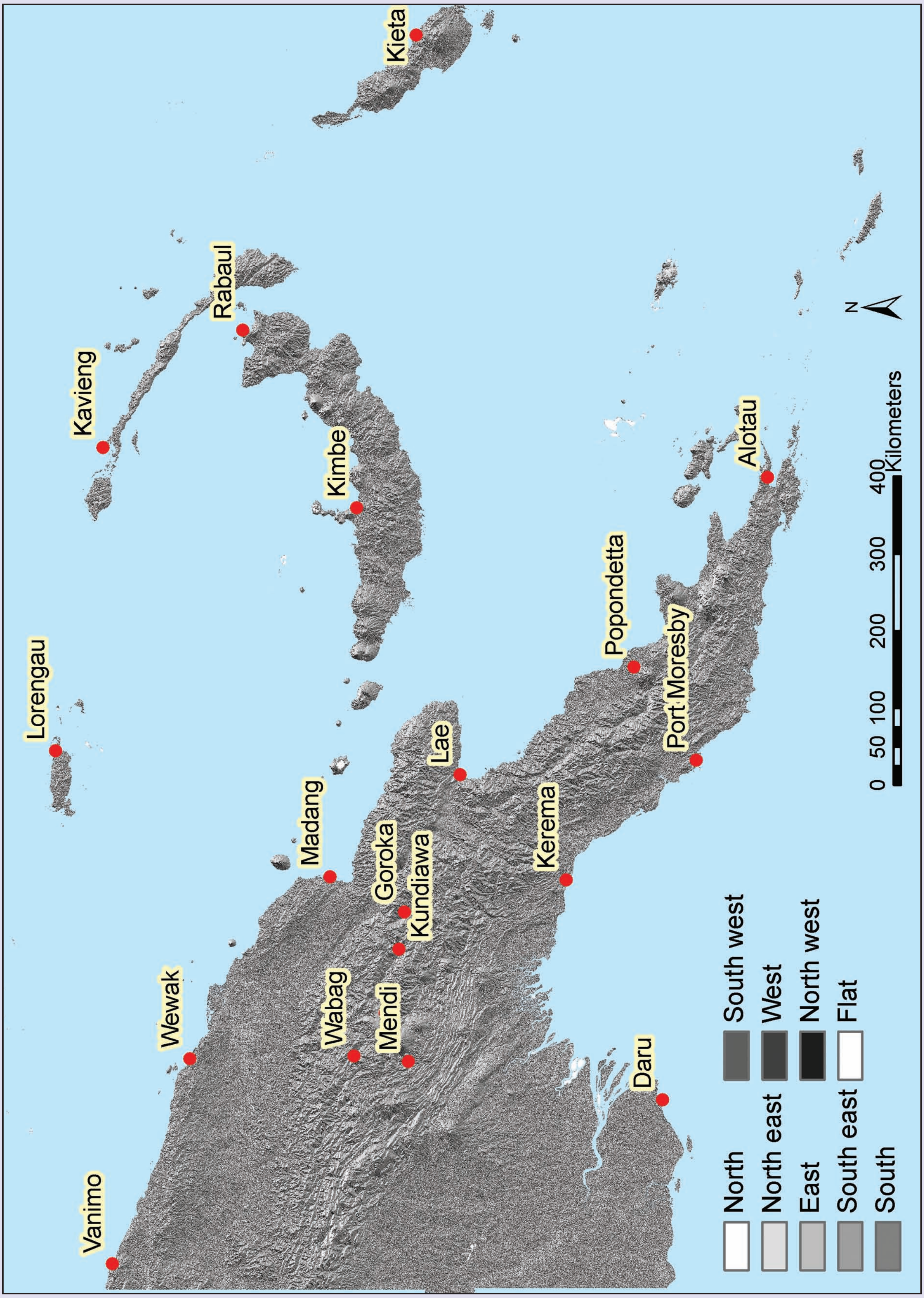
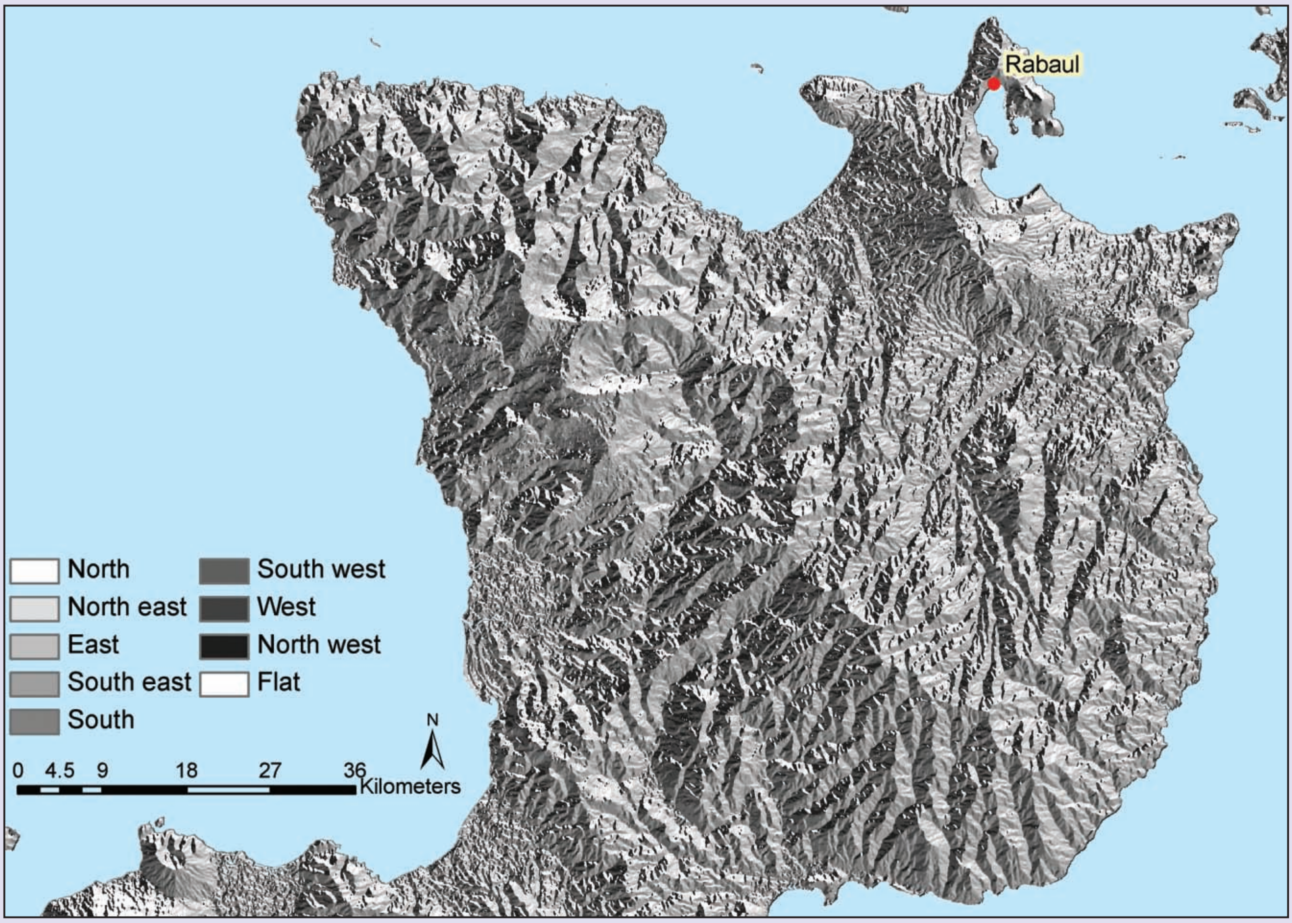


Figure 8: Aspect maps. Aspect describes the direction which a hill slope faces. This image shows aspect for the whole of PNG. The image on the following page shows a close-up view of the aspect map near Rabaul, East New Britain Province.



2.5.3 Data source and method

The aspect layer was generated from the digital elevation model described in section 2.2.2 using the 'aspect' command in the ESRI ArcInfo GIS. The resultant aspect raster was classified into the nine classes listed in Table 9 and converted into a MapInfo vector layer.

2.5.4 Limitations

As with slope (see section 2.4.5), the aspect map was created from a 90m DEM. For this reason rapid changes or small scale variation in aspect will not be apparent in the PNGRIS aspect map.

2.6 Landform

2.6.1 General discussion

Landform refers to the recurring pattern of topography within the landscape. The map of landform used in the PNGRIS upgrade is identical to the landform classification in the previous version of PNGRIS. As a result, the boundaries used to define landform are identical to the RMU boundaries. The scale of this layer is therefore identical to the scale of the previous version of PNGRIS, this being 1:500,000. The landform map of PNG is included in the PNGRIS Upgrade primarily because it aids interpretation of the topographic position map described in section 2.3. It should be used in conjunction with topographic position, as illustrated in Figure 5 from section 2.3 and also in Figure 9.

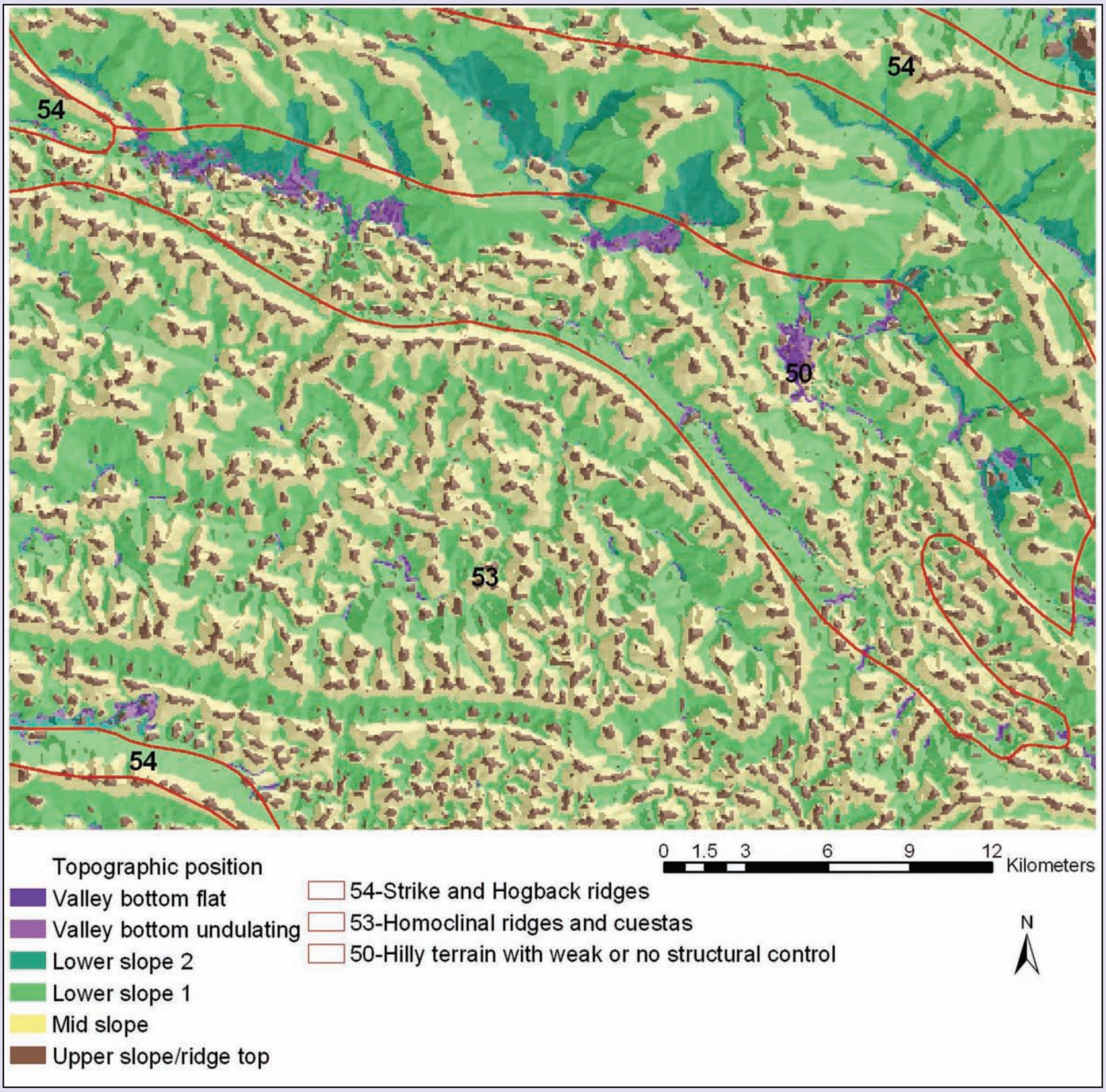


Figure 9: An example from Gulf Province showing the utility of combining the landform map with the topographic position map. The boundaries of each landform type are shown in red overlying the topographic position map. The landform map shows the broad pattern in the landscape, in this example Homoclinal ridges and cuestas. The topographic position map shows the location of the sharp ridges and scarps (brown) and gently inclined dipslopes (green) which make up the 'Homoclinal ridges and cuestas' landform type as described in section 2.7.7.3.

2.7 Landform type

This section discusses the method and data sources involved in producing the landform layer in PNGRIS, and was extracted from the handbook written for the previous version of PNGRIS (Bellamy & McAlpine, 1995).

2.7.1 Introduction

Landform type, in the sense used in this database, refers to the recurring pattern of topography in an RMU. It is one of the main criteria for delineating RMU's. A landform type is composed of a number of landform elements (or facets), some of which properties are defined separately in the database (namely, slope, soils). There may be many individual occurrences of each landform element in an RMU. Landform elements are relatively uniform pieces of land identifiable on aerial photographs or large-scale contour maps, but too small and numerous to delineate individually. Landform elements have a fairly uniform land-use potential and correspond to the minimum area of practical concern in this project.

2.7.2 Classification

2.7.2.1 General discussion

The landform classification used in the inventory and outlined in Table 6, is a broad genetic classification adopted from Löffler (1974). Although genetic criteria in themselves are not relevant to land-use assessment, a genetic classification of landform facilitates the extrapolation of data (particularly soils and slope) to unsurveyed parts of the country.

Thirty nine landform types are differentiated in the inventory and are divided into three major groups according to the dominant geomorphic processes by which they were formed:

- depositional landforms
- erosional landforms
- volcanic landforms

2.7.2.2 Depositional landforms

Depositional landforms are distinguished by the process involved in their formation and the environments they create. The two major groups differentiated here are littoral depositional and fluvial depositional landforms.

2.7.2.3 Erosional landforms

Erosional landforms are the most common and heterogeneous landform group, and include all landforms which have been subject to denudational processes for a considerable time. They are subdivided according to the dominant erosional processes involved in their formation into landforms of fluvial erosion and mass movement and landforms of karst erosion.

2.7.2.4 Volcanic landforms

Volcanic landforms are subdivided on the basis of differences in form and the degree and depth of dissection of the landform type.

2.7.2.5 Description of landform type

The following descriptions of the 39 landform types distinguished in the inventory are derived largely from the CSIRO Land Research Series (1964-76) publications and Loffler (1974; 1977). Most of the descriptions include a block diagram or plan of the landform type, which identifies its characteristic landform elements.

2.7.3 Data sources

The principal sources of information for the landform type attribute were:

- CSIRO Land Research Series (1964-76) publications;
- 1:1,000,000 Geomorphology map of PNG (Loffler, 1974);
- 1:1,000,000 Topographic Survey, PNG Series maps.

2.7.4 Method

The mapping and description of landform required compilation and extrapolation at a scale of 1:500,000 of information derived from the sources quoted in section 2.7.3 above.

In areas covered by the CSIRO Land Research Series (1964-76) publications, the accompanying 1:250,000 land system maps were reduced to a scale of 1:500,000, and relevant landform boundaries were derived. In areas not covered by theses maps, Loffler's (1974) 1:1,000,000 Geomorphology of PNG map and the 1:100,000 Topographic Survey maps were used to delineate the landform boundaries. The 1:100,000 Topographic Survey maps were also used to delineate some landform types, in particular fluvial and littoral depositional landforms, in greater detail than that provided by other sources.

The landform map was then fitted to the coastline represented by the orthorectified DEM described in section 2.2. The Landform map of PNG is shown in Figure 10.

Landform types are described below in section 2.7.5 to 2.7.10 in the order shown in Table 6. The number associated with each landform type is the code used to identify each landform type in the GIS database.

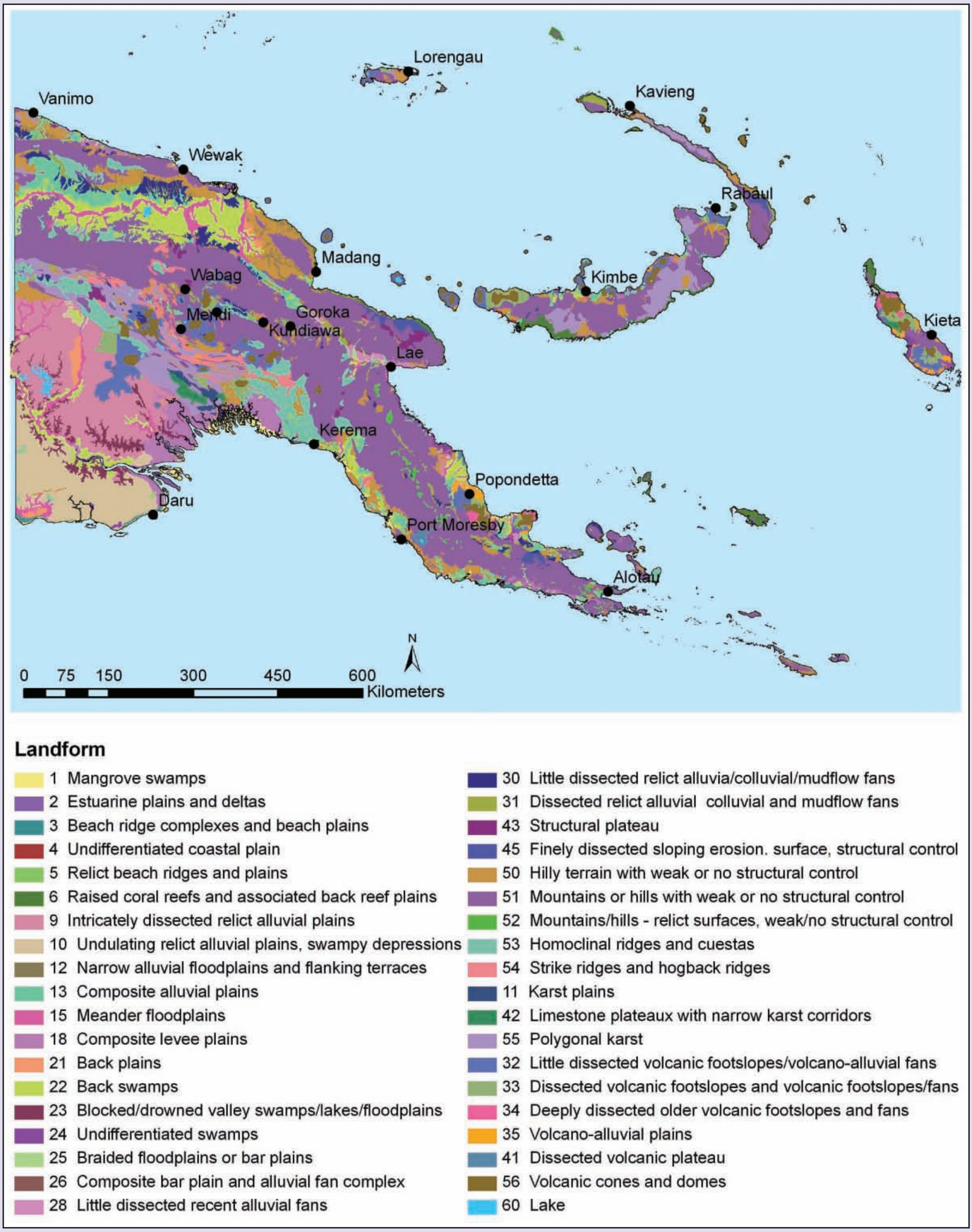


Figure 10: Landform map of PNG.

Table 6. Classification of landform type

CODE	DEPOSITIONAL LANDFORMS
	LITTORAL
	Recent
1	Mangrove swamps
2	Estuarine plains and deltas
3	Beach ridge complexes and beach plains
4	Undifferentiated coastal plain
	Relict
5	Relict beach ridges and plains
6	Raised coral reefs and associated back reef plains
	FLUVIAL
	Relict plains
9	Intricately dissected relict alluvial plains
10	Gently undulating relict alluvial plains with broad swampy drainage depressions
	Recent plains
12	Narrow alluvial floodplains and flanking terraces
13	Composite alluvial plains
15	Meander floodplains
18	Composite levee plains
21	Back plains
22	Back swamps
23	Blocked or drowned valley swamps and lakes and their associated swampy floodplains
24	Undifferentiated swamps
25	Braided floodplains or bar plains
	Recent fans
26	Composite bar plain and alluvial fan complex
28	Little dissected recent alluvial fans
	Relict fans
30	Little dissected or undissected relict alluvial, colluvial and mudflow fans
31	Dissected relict alluvial, colluvial and mudflow fans
	EROSIONAL LANDFORMS
	LANDFORMS OF FLUVIAL EROSION AND MASS MOVEMENT
	Structural surfaces
43	Structural plateau
45	Finely dissected sloping erosional surface with structural control
	Mountains and hills
50	Hilly terrain with weak or no structural control
51	Mountains or hills with weak or no structural control
52	Mountains and hills associated with relict surfaces with weak or no structural control
53	Homoclinal ridges and cuestas
54	Strike ridges and hogback ridges

	LANDFORMS OF KARST EROSION
	Plains
11	Karst plains
	Plateaux
42	Limestone plateaux with narrow karst corridors
	Mountains and hill
55	Polygonal karst
	VOLCANIC LANDFORMS
	Fans and footslopes
32	Little dissected volcanic footslopes and volcano-alluvial fans
33	Dissected volcanic footslopes and volcano-alluvial fans
34	Deeply dissected older volcanic footslopes and fans
35	Volcano-alluvial plains
	Plateaux
41	Dissected volcanic plateaux
	Mountains and hills
56	Volcanic cones and domes
	WATER BODIES
60	Lake

2.7.5 Littoral depositional landforms

2.7.5.1 Introduction

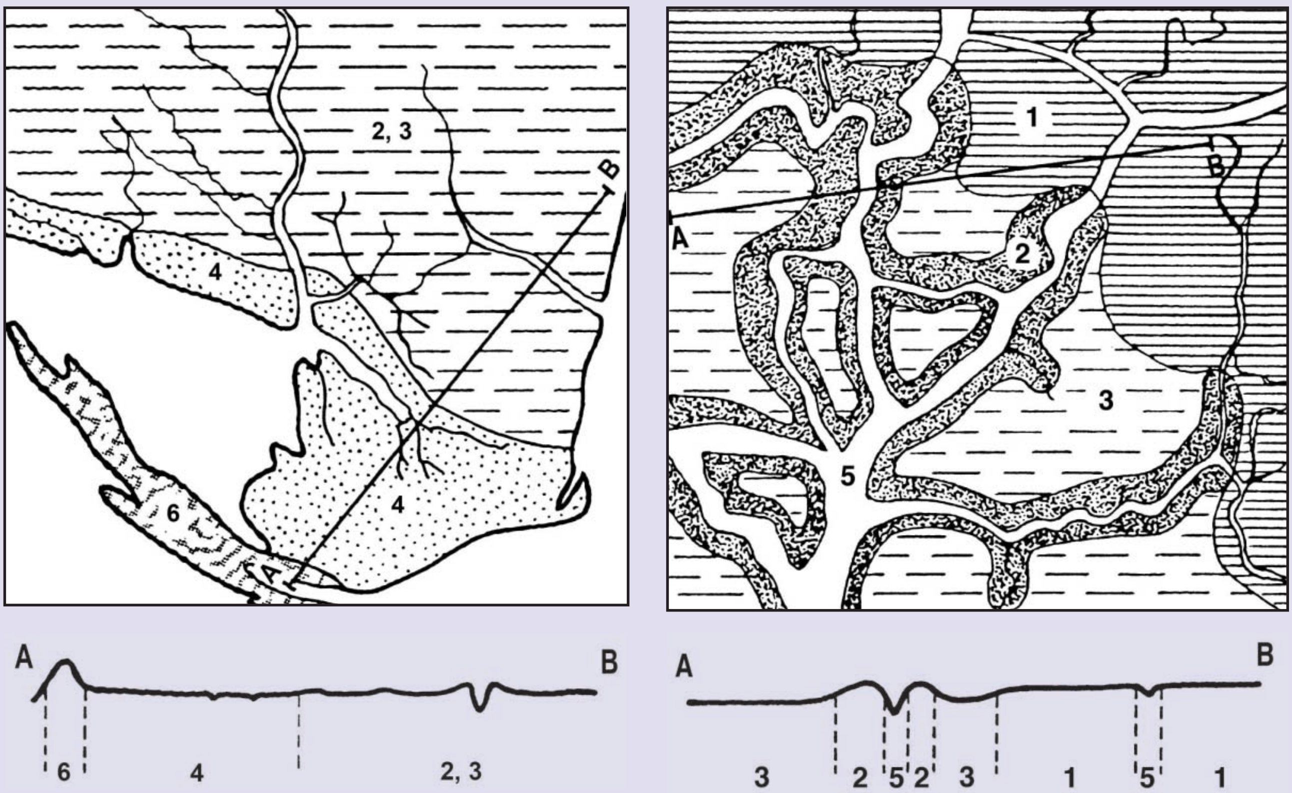
Littoral depositional landforms encompass three distinctive environments:

- the estuarine environment
- the beach ridge complex
- the uplifted coral reefs and terraces

In the inventory, littoral depositional landforms are subdivided on the basis of their age of formation (and consequently the degree of weathering) into recent and relict forms (Table 6). This distinction is taken from Loffler (1974, 1977). Recent littoral landforms refer to the littoral depositional landforms subject to active depositional processes on a large scale, such as mangrove swamps and beach ridge complexes. Littoral landforms that are no longer subject to active depositional processes, but are products of past environments no longer operative in a given area, are referred to as relict littoral landforms and encompass raised coral reefs and relict beach plains.

2.7.5.2 Recent littoral landforms

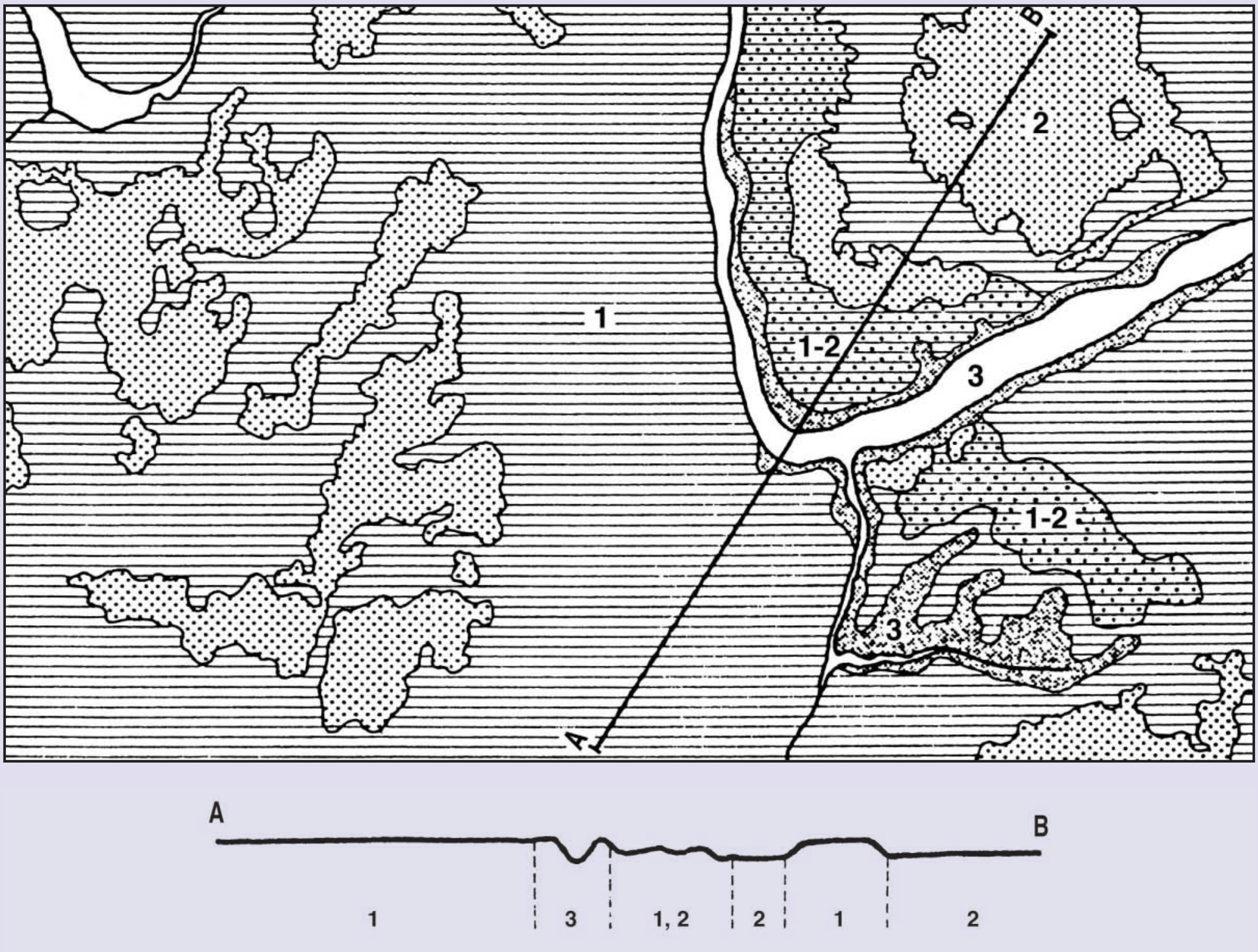
1 **Mangrove swamps** (Figure 11). Swampy interchannel tidal flats with raised margins and depressed centres are separated by funnel-shaped tidal channels. The tidal flats are covered with dense mangrove vegetation and subject to daily salt and brackish water inundation. Crab mounds are frequently abundant on the raised rims but rapidly decrease in abundance away from the tidal channels. The tidal flats are composed of estuarine and lagoonal mud, silt and sand with local peat. Small inclusions of beach ridges may be present locally within the tidal flats. Mangrove swamps generally form the seaward extension of the inland alluvial plains, but with tidal drainage consisting of a dense interconnected network of slowly migrating open-ended channels. Mangroves favour estuaries, carrying large quantities of fine sediments, and gently shelving coastlines are protected from strong currents and wave action. Beach ridge complexes and beach plains (Figure 12, Figure 13). Long parallel sand ridges and swales (depressions), are most prominent near the coast where they reach up to 2m high, but gradually decreased in height inland to form a level or gently undulating sand plain. The swales between the beach ridges are generally swampy, and may be tidal with sinuous tidal creeks or non-tidal with standing water. Irregular sand dunes up to 3m high may be locally present on the outermost beach ridge. The level to gently undulating beach plain has extremely low relief (less than 1m) with slopes of less than 1^{o} and stream channels are absent or rare. Present beaches, sand spits and bars, and tidal flats or non-tidal swamps are included in this landform type also grow in firm clay, peat, sand and even coral detritus, provided the environment is tidal.



1. Upper tidal flat transitional to freshwater environment
2. Raise margins of interchannel flats
3. Central depresion of interchannel flat
4. Lower tidal flats
5. Tidal channel of estuary
6. Sandy beach spit of bar

Figure 11: Mangrove swamps in the Purari delta (Gulf Province) with funnel-shaped estuarine channels and a reticulated interconnected channel network typical for tropical mangrove swamps. The vegetation consists predominantly of Rhizophora (green) and Bruguiera (yellow). Some small village settlements may be seen bordering channels in the centre of the image.

2 **Estuarine plains** (Figure 12). Swampy interchannel tidal flat and/or hummocky littoral back plains are traversed by tidal channels. These plains are not subject to daily tidal inundation but to irregular freshwater flooding from rivers and creeks. Water table levels remain above the surface throughout the year and locally, some areas may be subject to slight tidal influence. In many places, the estuarine plains form the inland transition zone from the mangrove to the freshwater environment. They are essentially the seaward extensions of alluvial plains. Newly formed estuarine plains include emerging mud banks in estuaries, alluvial scrolls on meander bends and degraded beach plains. Estuarine plains along the southern PNG coastline are typically interchannel tidal flats with raised margins and depressed centres, separated by open ended tidal channels, and predominantly covered with nipa palm vegetation. Crab mounds are abundant near channel margins and in places coalesce to form islands up to 20m^2 in area separated by narrow tidal channels. These mounds are of great importance to the local population as they are used to grow foodstuffs. Estuarine plains along the northern PNG coastline are typically swampy flat to hummocky back plains subject to severe seasonal flooding and mainly draining to and extending inland along large tidal channels. These plains locally include low scrolls, levees, and oxbow and floodplain lakes.



1. Swampy plains with flat or hommocky surfaces
2. Slightly lower and poorly drained plains
3. Narrow tidal creeks lined with nipa palm or mangrove vegetation

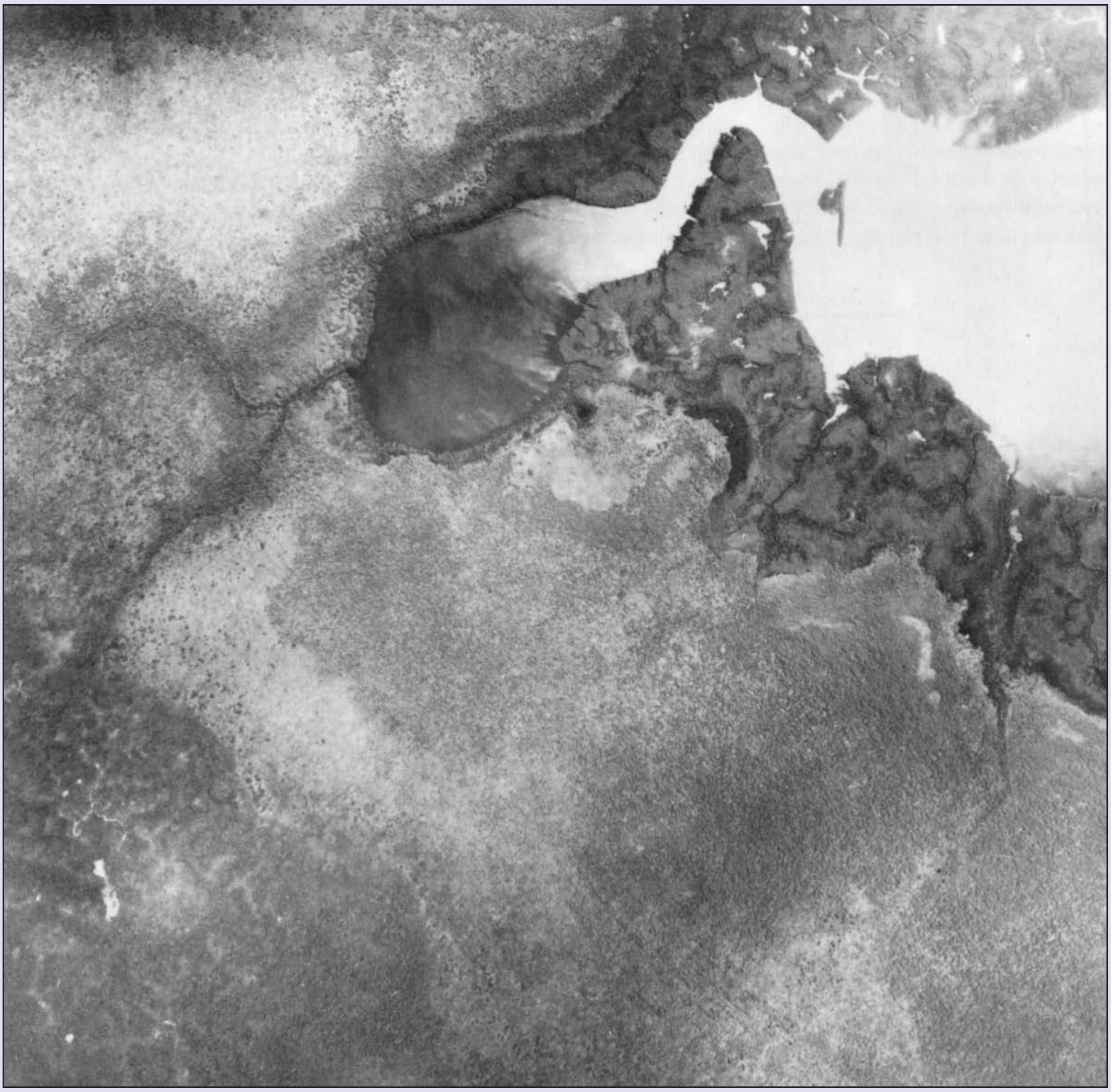
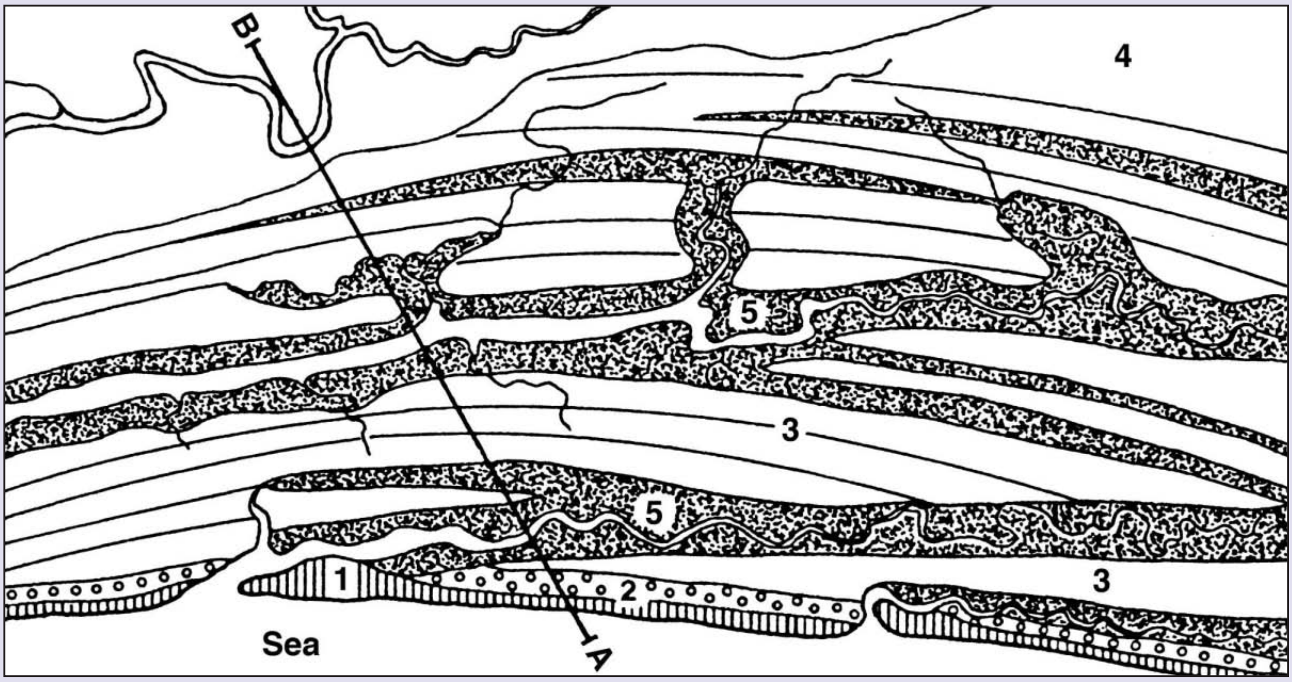
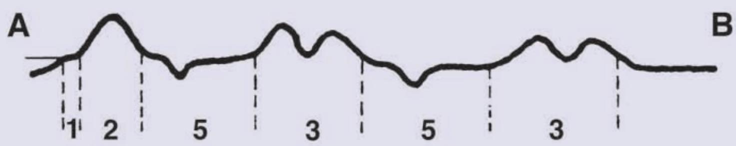


Figure 12: Estuarine plains and mangrove swamps of the Sepik River delta (East Sepik Province). Large tidal mudbanks (dark toned areas), bordering the Murik saltwater tidal lagoons, are covered with raw peats derived from the predominantly mangrove woodland vegetation. These mangrove swamps are below high tide mark and include branching tidal creeks. Level to hummocky swampy estuarine plains (lighter-toned areas), form the inland transition zone from the mangrove swamps to the freshwater environment. These estuarine plains are subject to freshwater flooding from the mainland, with a water table permanently above the land surface and vegetation consisting of a complex of swamp forest, swamp woodland, and some herbaceous swamp communities.

3 Beach ridge complexes and beach plains (Figure 13, Figure 14). Long parallel sand ridges and swales (depressions) are most prominent near the coast where they reach up to 2m high, but gradually decreasing in height inland to form a level or gently undulating sand plain. The swales between the beach ridges are generally swampy, and may be tidal with sinuous tidal creeks or non-tidal with standing water. Irregular sand dunes up to 3m high may be locally present on the outermost beach ridge. The level to gently undulating beach plain has extremely low relief (less than 1m) with slopes of less than 1º and stream channels are absent or rare. Present beaches, sand spits and bars, and tidal flats or non-tidal swamps are included in this landform type.



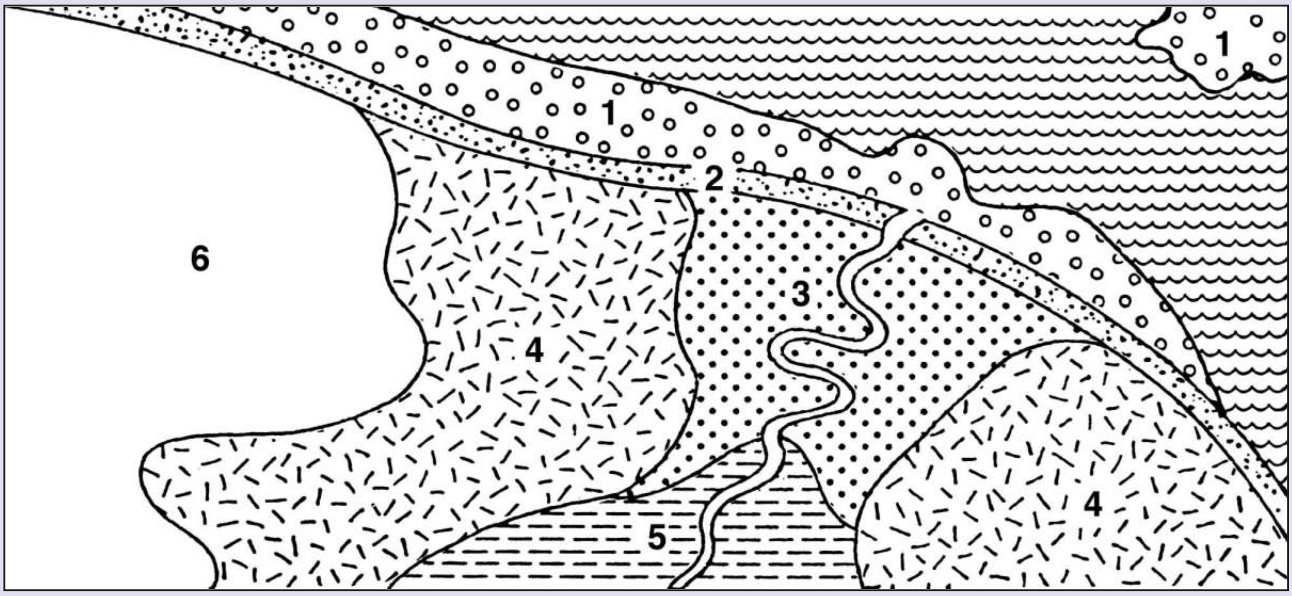


1. Present sandy beaches, spits and off-shore bars
2. Present beach ridges (may be active or stable) with slopes up to 10º, and occational sand dunes up to 3m high
3. Inland beach ridges and swales aligned parallel to coast
4. Degraded beach ridges and flat beach plains with slopes of less than 1º
5. Swampy or waterlogged depressions (swales) between ridges

Figure 13. Beach ridges, spits and bars with mangrove flats at Levi Inlet. The sandy spit is extending north-westward (bottom right) gradually closing off the inlet. Inside the mangrove flat is an older beach ridge complex, an indication of the gradual seaward advance. The beach ridges are preferred sites for settlements and are also extensively used as garden land.

Figure 14: Beach ridge and swale complex built mainly of volcanic sand at Moila Point, Bougainville Island. Dunes are not present but successively constructed low beach ridges form barrier systems. Peaty sand swales colonized by Hanguana and some nipa palms occur between sandy beach ridges. Pioneering communities occur on the ridges, the outer ridges support Cerbera–Calophyllum mid-height forest and the inner ridges Vitex-metia tall forest.

4 **Undifferentiated coastal plain** (Figure 15). Complex of tidal flats, coral reefs, sandy beaches, low emerged coral platforms and small alluvial plains generally forming an irregular coast with narrow discontinuous beaches protected by either fringing or barrier coral reefs, or outer mangrove flats, with tidal flats and brackish swamps in bays and inlets. Small low angle alluvial plains may be present on the landward margin and are frequently backed by higher coral platforms (particularly in the island Provinces or on higher alluvial plains).

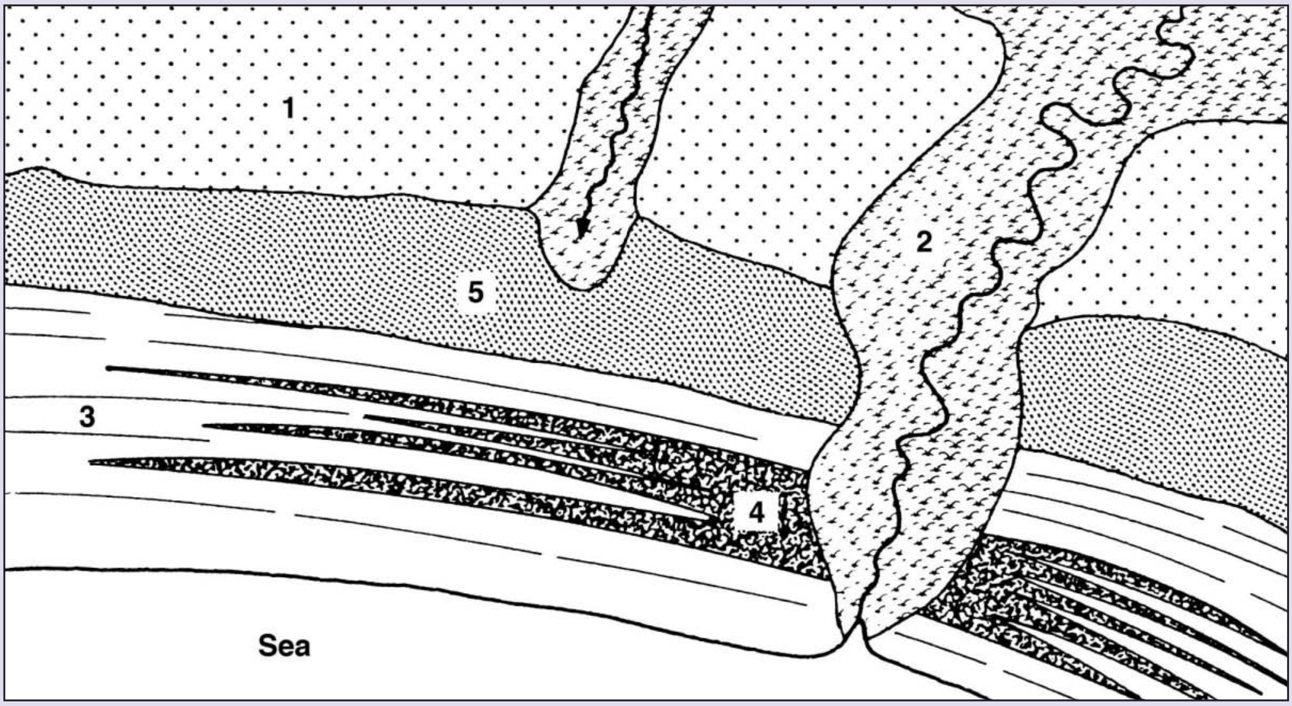


1. Coral reef and/or mangrove flats
2. Narrow gently sloping sandy beach
3. Tidal flats, mangrove swamps
4. Freshwater to brackish swamps
5. Alluvial palin traversed by small sinuous streams
6. Raised coral platform or higher alluvial plains

Figure 15: Coastal plain south of Kieta with a raised coral reef backed by tidal flats and a low angle alluvial plain.

2.7.5.3 Relict littoral landforms

5 **Relict beach ridge complex** (Figure 16). Level to gently undulating sandy beach plains of extremely low relief, consisting of a raised beach ridge barrier with ridges and swales in various stages of degradation to flat plains. Locally level alluvial flats occur adjacent to sinuous stream channels and small freshwater swamps may be impounded between the degraded beach ridges and the flat beach plain. Usually relict beach ridges are found some distance inland and separated from the present beach ridge complex.

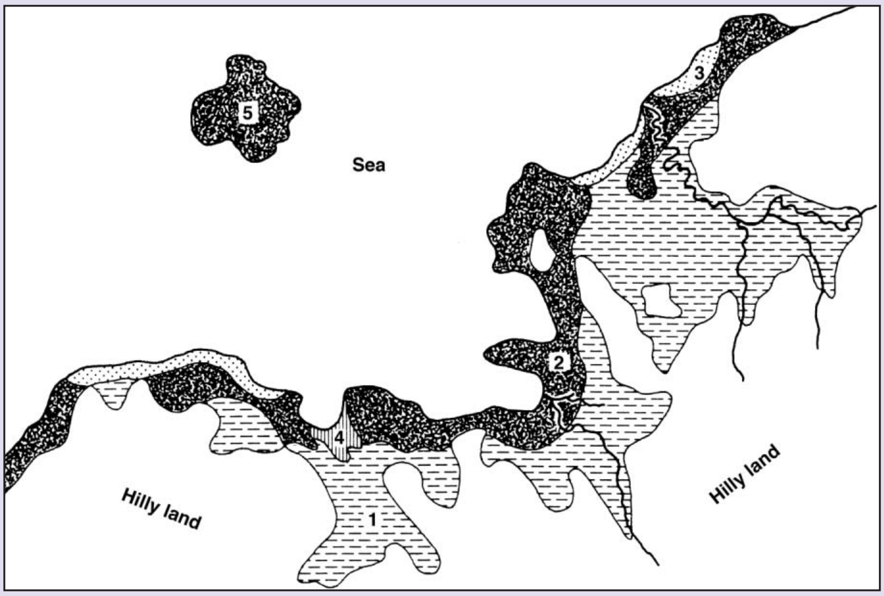


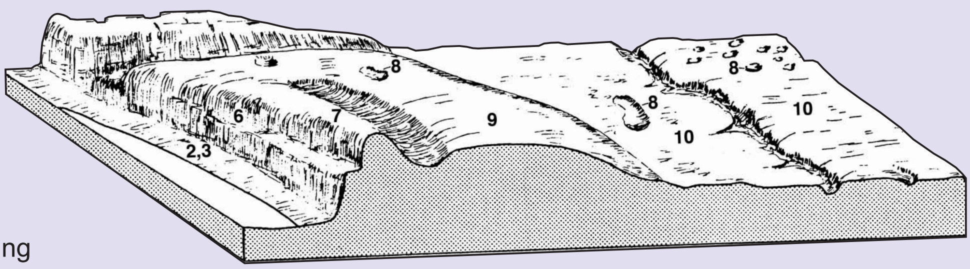
1. Flat sandy beach plain
2. Alluvial flats adjacent to sinuous channels
3. Degraded beach ridge slopes less than 1º
4. Swales between ridges
5. Permanent swamp or degraded beach ridges

Figure 16: Relict beach ridge plain near Malalaua, Gulf Province, with large to medium-crowned forest partly cleared and burnt to form mid-height Imperata grassland.

6 **Raised coral reefs and associated back reef plains** (Figure 17) take a variety of forms:

- narrow uplifted coastal plains in front of steeply rising hinterlands (e.g. along the northern coast of the PNG mainland) consisting of poorly drained floodplain with swampy depressions traversed by small meandering rivers with discontinuous low terraces, and higher raised coral platforms on the inner margin.
- More extensive raised coral reef platforms comprising little dissected level to undulating plains with scattered swampy dolines and occasional former island ridges up to 30m high, and bounded on the seaward margin by precipitous scarps up to 100m high (e.g. Buka Is. and Trobriand Is.).
- Spectacular staircase-like raised coral terrace sequences up to 700m above sea level along the Huon Peninsula, up to 500m on the south coast of New Britain, and up to 400m along the north-west coast of New Ireland and New Hanover.
- An uplifted reef surface continuing inland as a marine depositional plain formed on soft calcareous sediments, such as in the western part of New Britain.





1. Flat or gently undulating floodplains extending into river valleys
2. Raised coral reefs either flat to gently undulating or with slightly stepped surfaces
3. Sandy beach ridges and swales
4. Swampy depresions
5. Raised coral reef platforms forming offshore islands
6. Precipitous or cliffed scarp with occasional perched benches
7. Steep discontinous ridge and trough
8. Dolines
9. Plain with gentle inland slopes
10. Lower plain of former coral lagoon

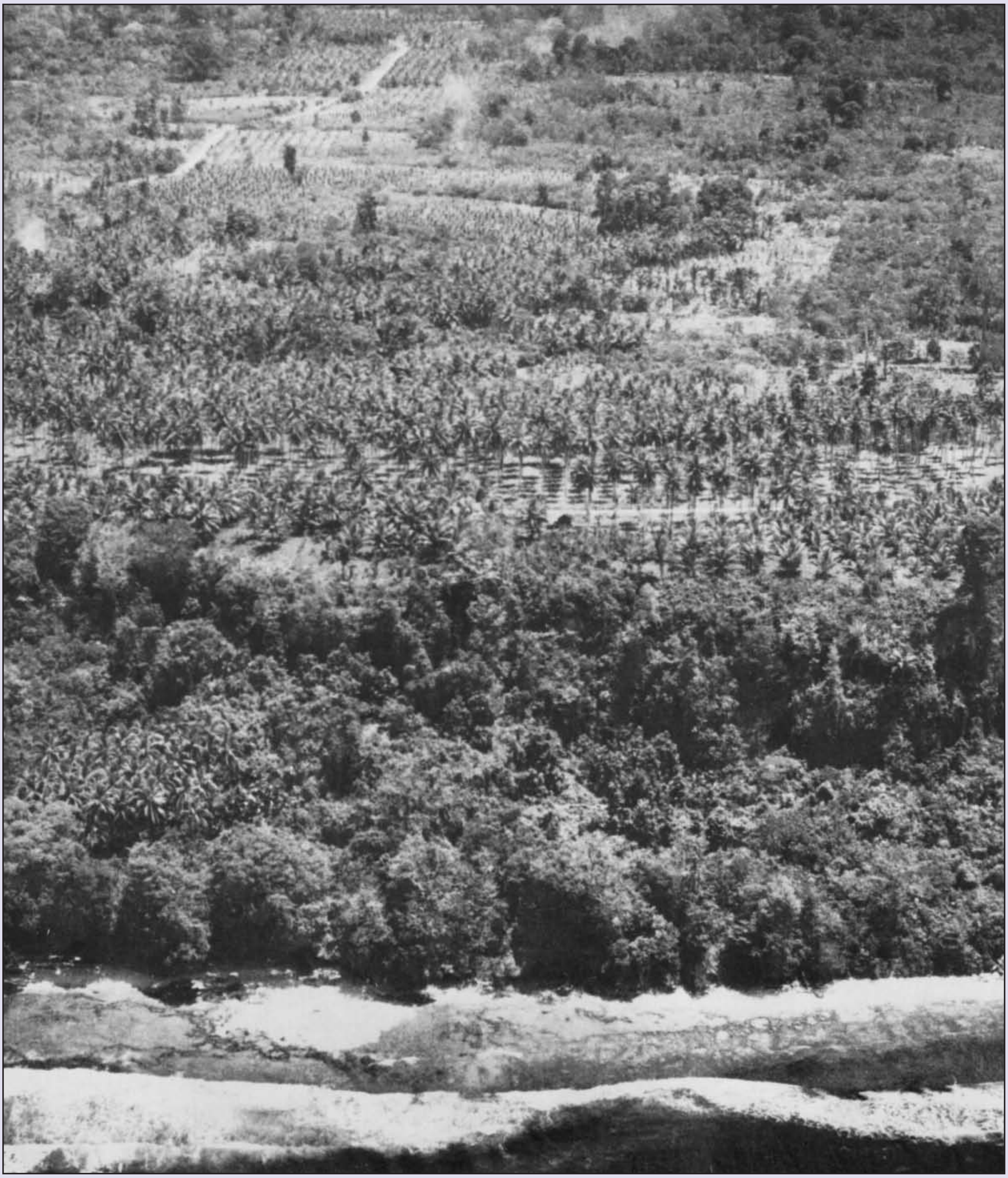


Figure 17: Raised coral reef platform consisting of an upwarped Pleistocene coral reef rising precipitously at the coast to over 80 metres in many places. This view of the east coast of Buka Island near Lonahan shows a precipitous cliff rising sharply behind sandy beaches to a high, gently sloping to undulating plain with its characteristic densely cultivated pattern of coconut plantations, gardens and regrowth.

2.7.6 Fluvial depositional landforms

2.7.6.1 Introduction

Fluvial depositional landforms include closely related and often transitional types of alluvial plains and fans. Alluvial fans are built up by braiding streams while alluvial plains are formed predominantly by lateral accretion and overbank deposition by streams flowing in defined though migrating channels. In addition, alluvial plains usually slope more gently than fans.

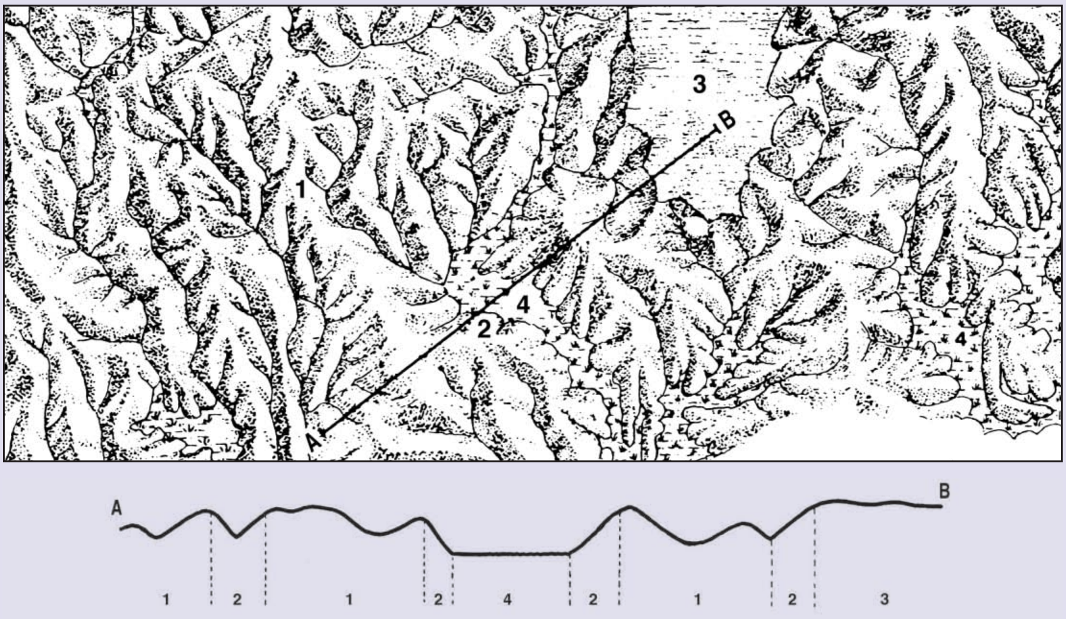
The fluvial depositional landforms are subdivided on the basis of age of formation into recent and relict forms. The distinction between recent and relict depositional landforms is taken from Loffler (1974, 1977). Recent depositional landforms refer to fluvial depositional landforms subject to active depositional processes on a large scale. The eleven categories for recent plains and fans (Table 11) are distinguished on the basis of their topographic form. Most recent alluvial plains in Papua New Guinea consist of a central floodplain and wide marginal plains. Where possible the floodplains are mapped separately from their associated back plains as they represent a distinctly different environment. Where small size is a limiting factor and only the whole complex could be mapped at a scale of 1:500,000, they are classified as composite alluvial plains (landform types 13 and 18).

Fluvial depositional landforms that are above present flood level following tectonic events, changes in base level or fluvial regime, and are therefore no longer subject to active depositional processes are referred to as relict depositional landforms. Relict landforms are products of past environments no longer operative in a given area, and they include alluvial fans, plains and terraces. The relict landforms are in varying stages of dissection and are thus transitional between depositional and erosional landforms, but their character as depositional plains or fans is still apparent in the form of undulation plain land or intricately dissected plains or fans with even summit levels. Relict plains and fans are sub-divided in the database on the basis of the degree of dissection and, consequently to some extent the degree of weathering.

The distinction between active and relict fans is sometimes difficult to draw as certain areas of a fan may be active while other parts of the same fan may be relict. The boundaries drawn are therefore arbitrary in some cases.

2.7.6.2 Relict plains

9 **Intricately dissected relict alluvial plain** (Figure 18). Dissected former alluvial plains, consisting of numerous low closely spaced ridges and narrow valleys with minor undulating plateau remnants in watershed areas. Characteristically the summit levels of the ridges are very even, forming a perfect plain sloping consistently in one direction. Relief is very low, and slopes vary mostly between 5 and 20º. The closely spaced dendritic drainage network consists of flat-bottomed swampy major floodplains and narrow V-shaped tributary valleys. Slumping, gullying and tunneling are common.



1. Low undulating ridge crests, typical slopes up to 3º
2. Hill slopes, average slope 8 to 10º
3. Undulating plateau remnants, slopes up to 3º
4. Flat swampy or water logged valley floors

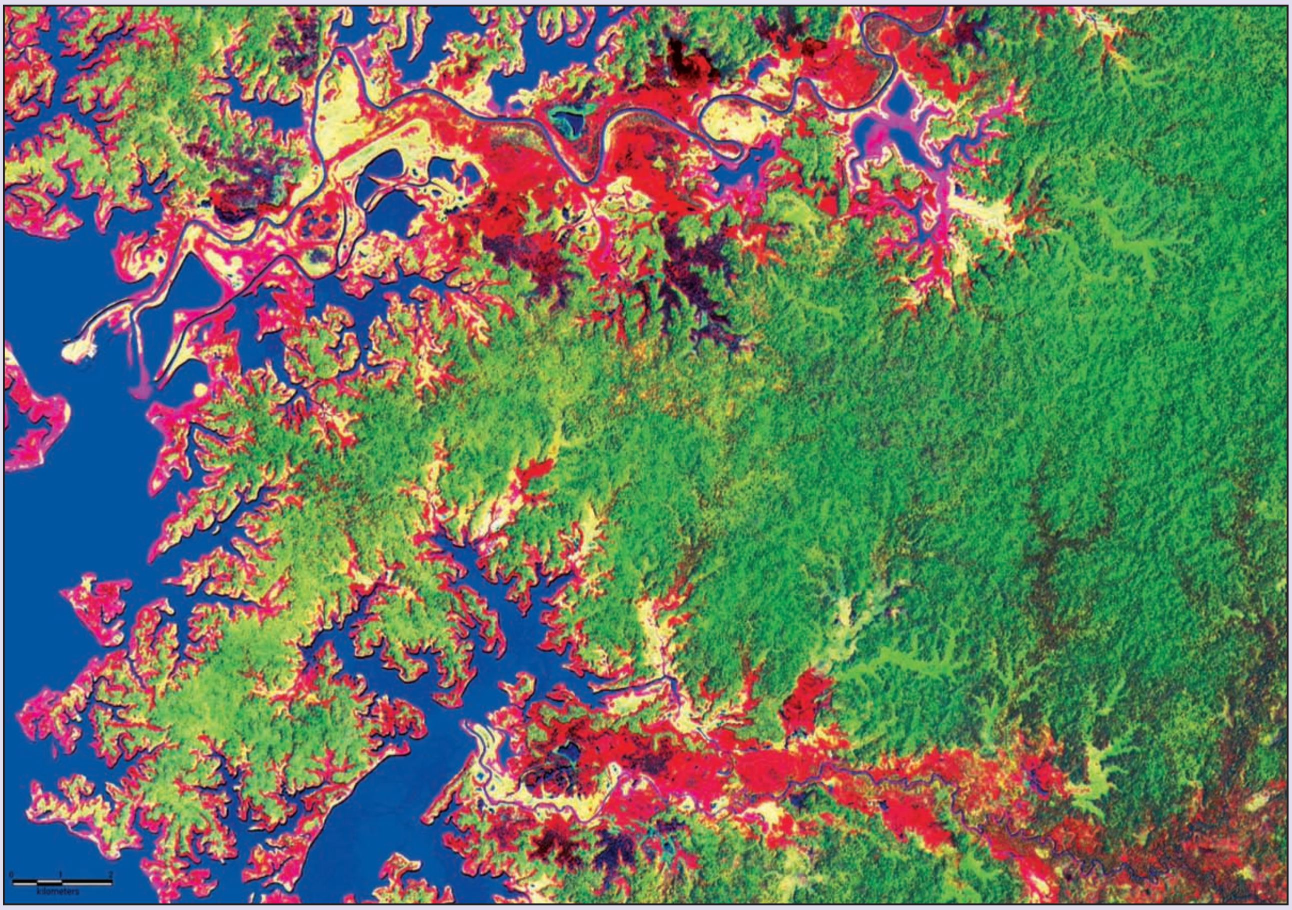
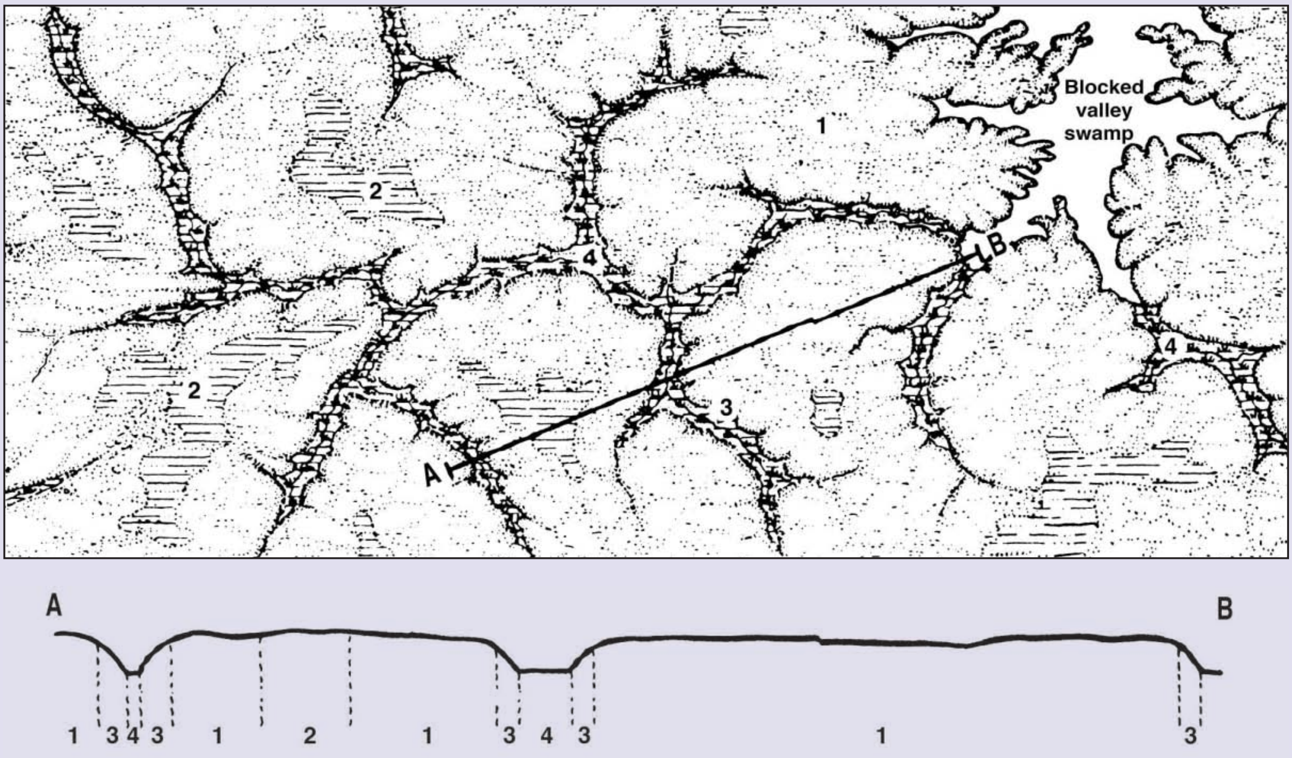
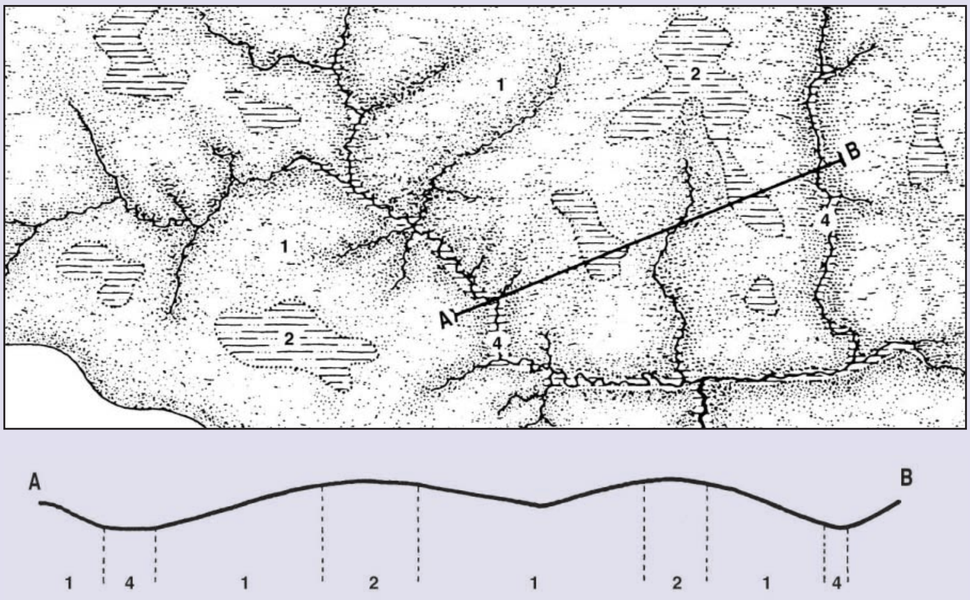


Figure 18: Part of the extensive dissected relict alluvial plain north of the lower Strickland River with an intricate pattern of closely spaced low ridges and a dense drainage system. Several blocked valley swamps and submerged levees of a tributary to Lake Murray may be seen in the northern part of the image.

10 Gently undulating relict alluvial plains (Figure 19). Little dissected former alluvial plains constituting for the most part a flat to gently undulating low-lying plateau with local relief generally less than 10m. The relict plain consists largely of better drained, gently undulating terrain not subject to wet season inundation with smaller poorly drained flat watershed areas subject to wet season water logging. Streams are widely spaced with open V-shaped or swampy flat-bottomed valleys and narrow floodplains present locally. Slopes are generally smooth and less than 2º but may be up to 12º on short slopes near rivers.





1. Flat to gently undulating plain, slopes 0 to 3º
2. Flat plain on local watersheds, slopes less than 1º, poorly drained
3. Short slopes on valley sides, 2 to 12º
4. Open V-shaped or flat, swampy valley floors

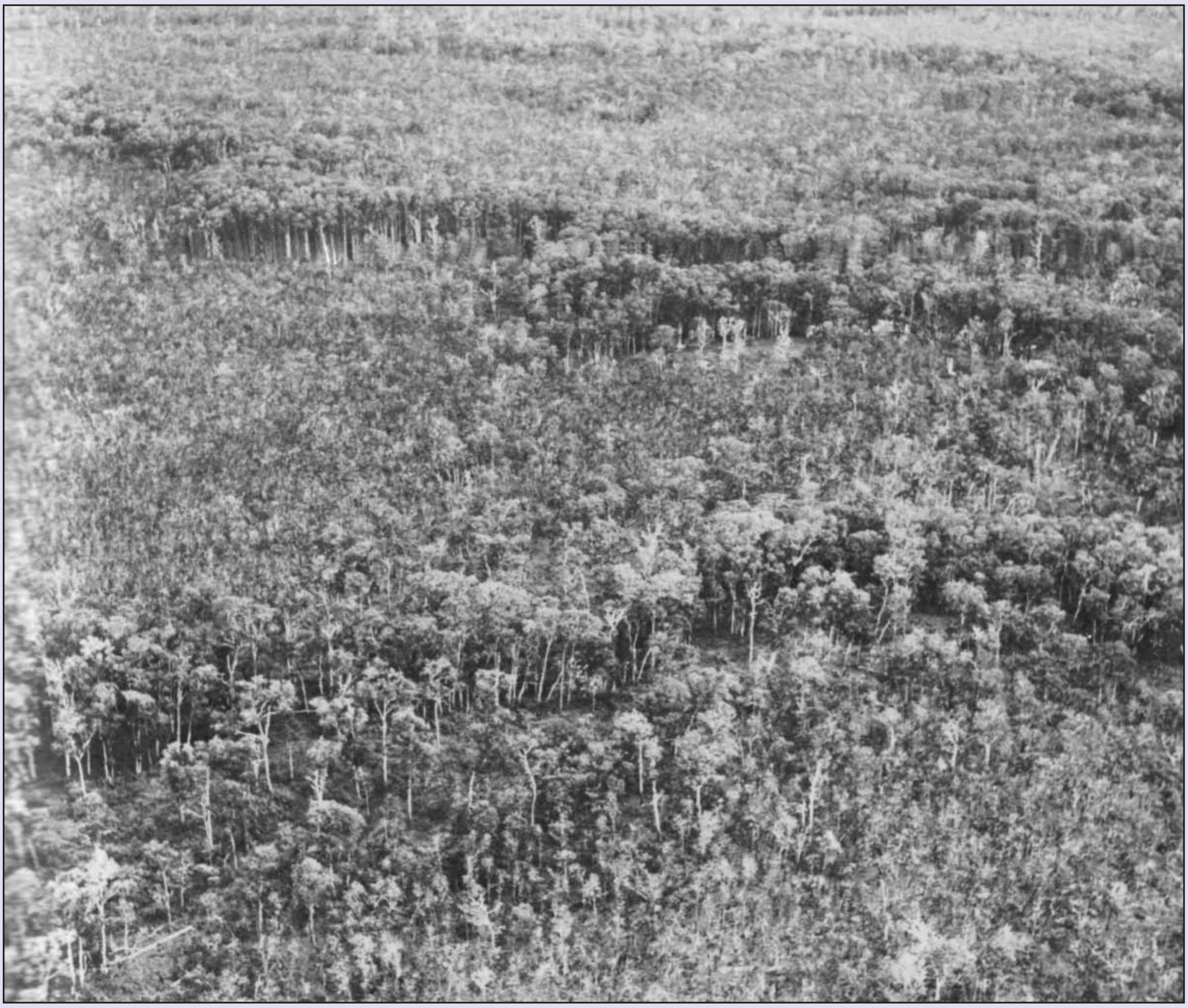
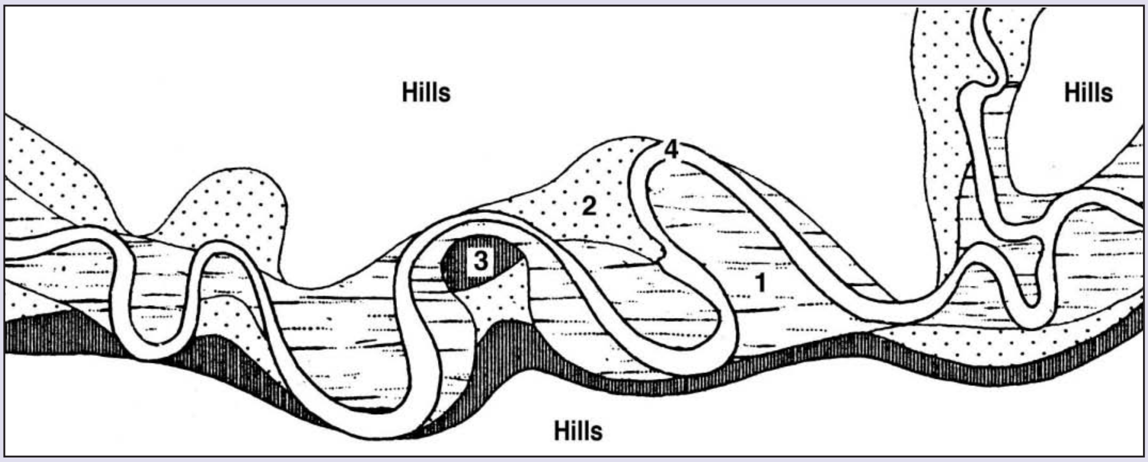


Figure 19: An extensive little dissected relict alluvial plain south of the Fly River (Western Province) forming a gently undulating plain of very low gradient. The relict plain is covered in Melaleuca savannah with drainage lines revealed by gallery woodland, which is taller, denser and darker toned than the surrounding savannah.

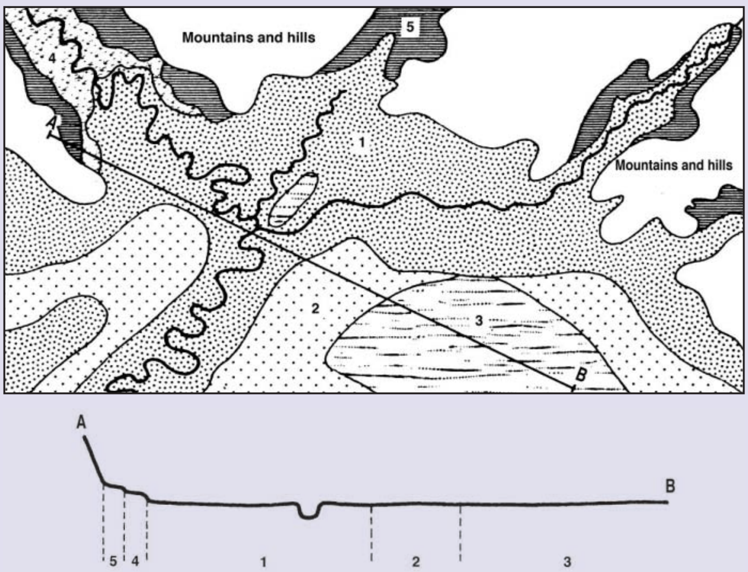
2.7.6.3 Recent alluvial plains

12 Narrow alluvial plains. Small alluvial valley plains with narrow floodplains and flanking terraces along meandering river channels in confined valleys of hilly or mountainous areas. The narrow floodplains are flat to gently undulating, hummocky surfaces in narrow tracts adjacent to river channels.They are subject to short flash flooding and are flanked by low discontinuous terraces. The meandering river channels are locally braided and may include small scroll plains. Higher river terraces are generally well developed with flat to very gently undulating surfaces with steep marginal slopes and well drained by shallow creeks.



1. Narrow, flat to gently undulating floodplains subject to flash flooding
2. Low discontinuous terraces
3. Higher terraces, well drained
4. Meandering or braided river channels

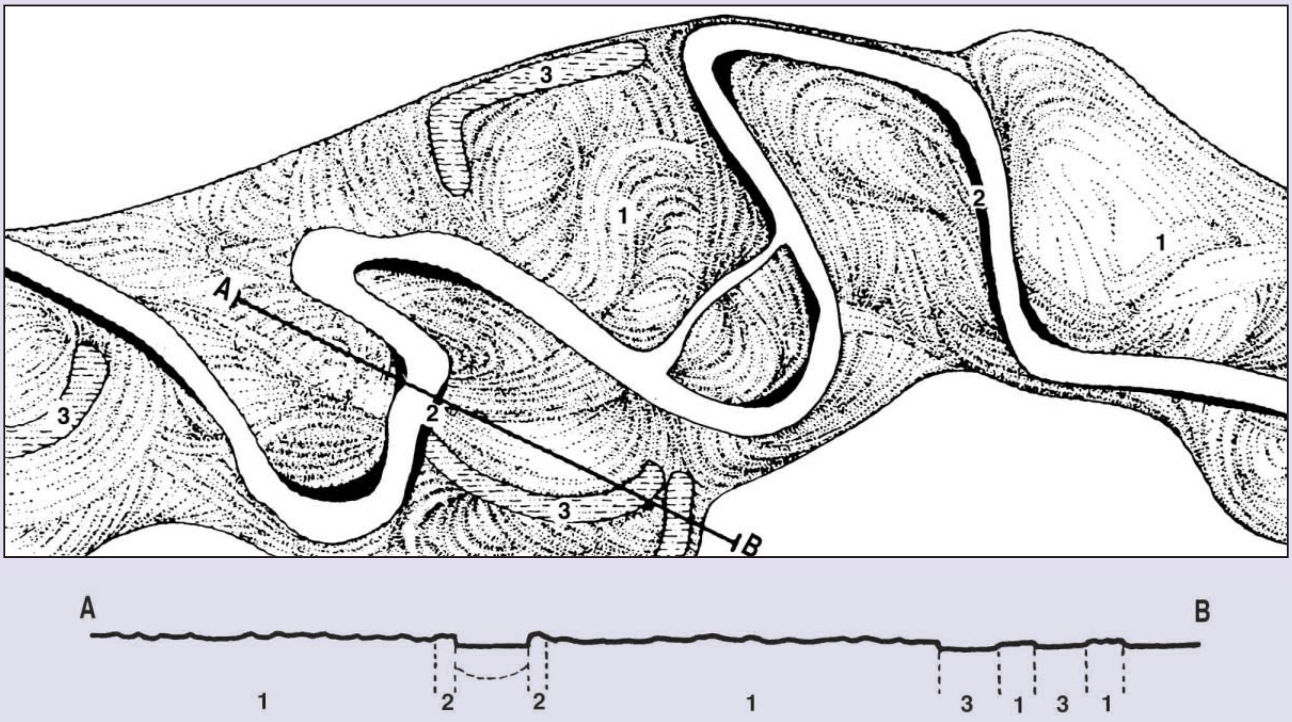
13 Composite alluvial plains (Figure 20). Complex alluvial plains or basins consisting of a central flat to gently undulating meander floodplain with meandering stream channels, low discontinuous levees, meander scrolls and oxbows, which merge into poorly drained flanking back plains and back swamps, and/or higher well drained terraces. The alluvial plains are comprised of sediment deposited during lateral migration and overbank deposition of streams flowing in defined though migrating channels. The drainage status of this landform type varies greatly, depending on local conditions, from poorly to well drained.



1. Flat to very gently undulating floodplains with swampy oxbows
2. Unchannelled back plains and tributary plains, smooth to hummocky, very poorly drained
3. Back swamps and swampy flats
4. Open V-shaped or flat, swampy valley floors

Figure 20: Oblique aerial photograph of the intermontane basin of the Andabare River, Southern Highlands Province. This swampy alluviated upland valley is a composite alluvial plain surrounded by dissected slopes and fans on less resistant sedimentary rocks covered with natural grassland, and flanked by steep north-westerly trending hogback ridges on limestone with lower montane forest.

15 **Meander flood plains** (Figure 21). Unstable depositional alluvial plains rising slightly above the marginal back plains, swamps and lakes, subject to frequent flooding, and consisting predominantly of a slowly migrating and highly meandering stream channel, numerous cut-off meanders forming oxbow lakes and swamps, low discontinuous levees, point bars and many scroll complexes. The meanders move freely and frequently within the meander belt but the main channel can also completely alter its course by forming a new floodplain across the flanking plain. In the upper parts of the floodplain, where the stream leaves the mountain, the streams frequently develop braids, while along the lower courses levees become more prominent, replacing point bars, and may become continuous.



1. Scroll complexes, i.e. patterns of crescentric ridges and swales above low water level but subject to prolonged flooding in the wet season
2. Discontinuous levee banks and present scrolls with gentle back slopes but above low water level, and mostly inunudated in the wet season
3. Permanent swamps, lakes and oxbows

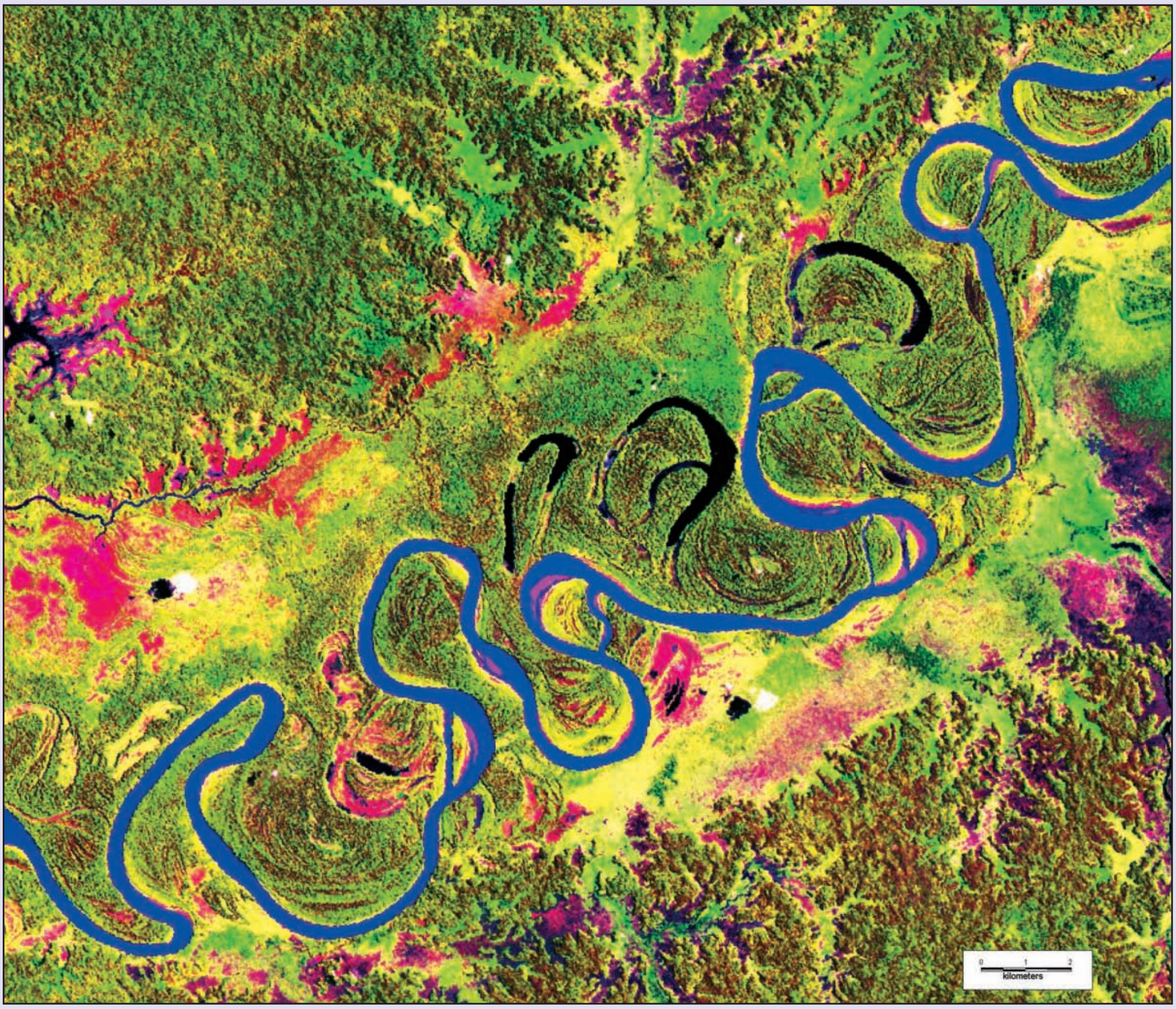
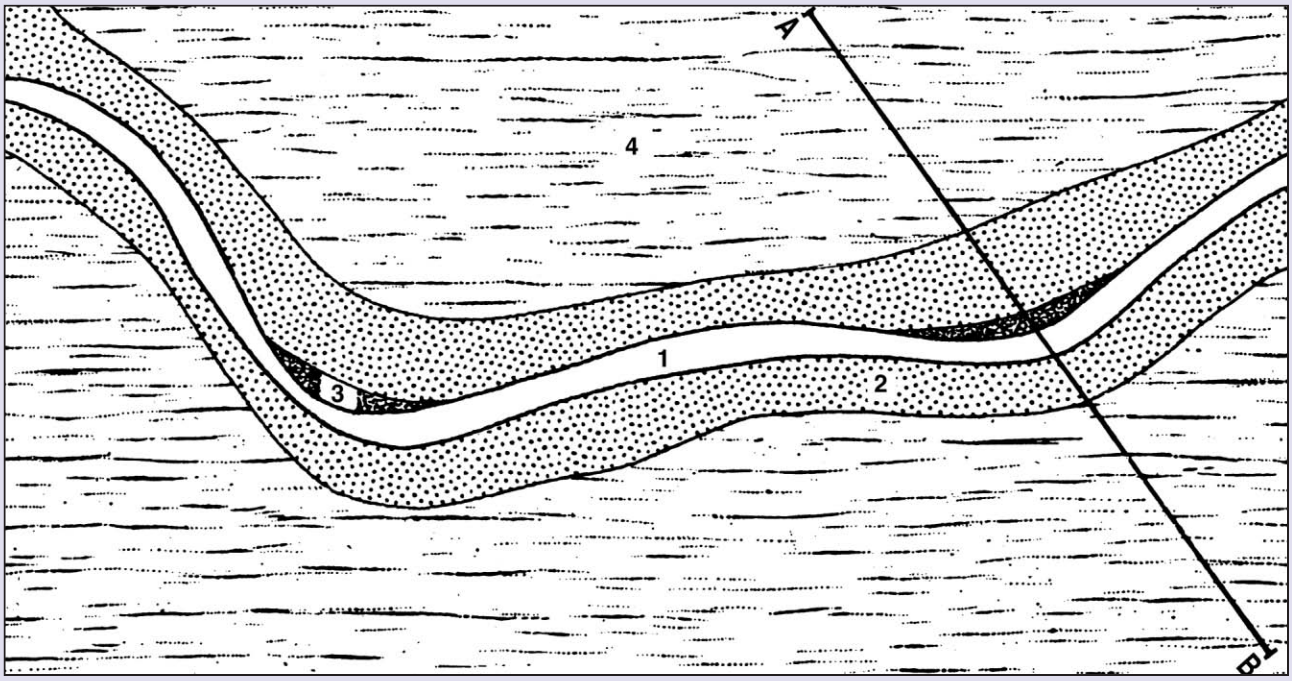


Figure 21: Meander floodplains typical of the middle and lower courses of major rivers such as the Fly and Sepik Rivers and their tributaries. The satellite image shows a section of the lower Strickland River. The meander floodplains are characterized by a meandering channel, oxbows, scroll complexes and back swamps and lakes. Long and narrow scroll ridges covered with waterlogged pioneering open forest alternate with depressions that have a vegetation of swamp grasses. Depending on their age, some of the abandoned meanders have open water with or without aquatic vegetation, some have swamp grass and some have climber thicket with scattered trees. Extensive back swamps, subject to frequent deep flooding (centre) are slightly lower than the meander floodplain and scroll complexes and are covered with floating grasses and savannah.

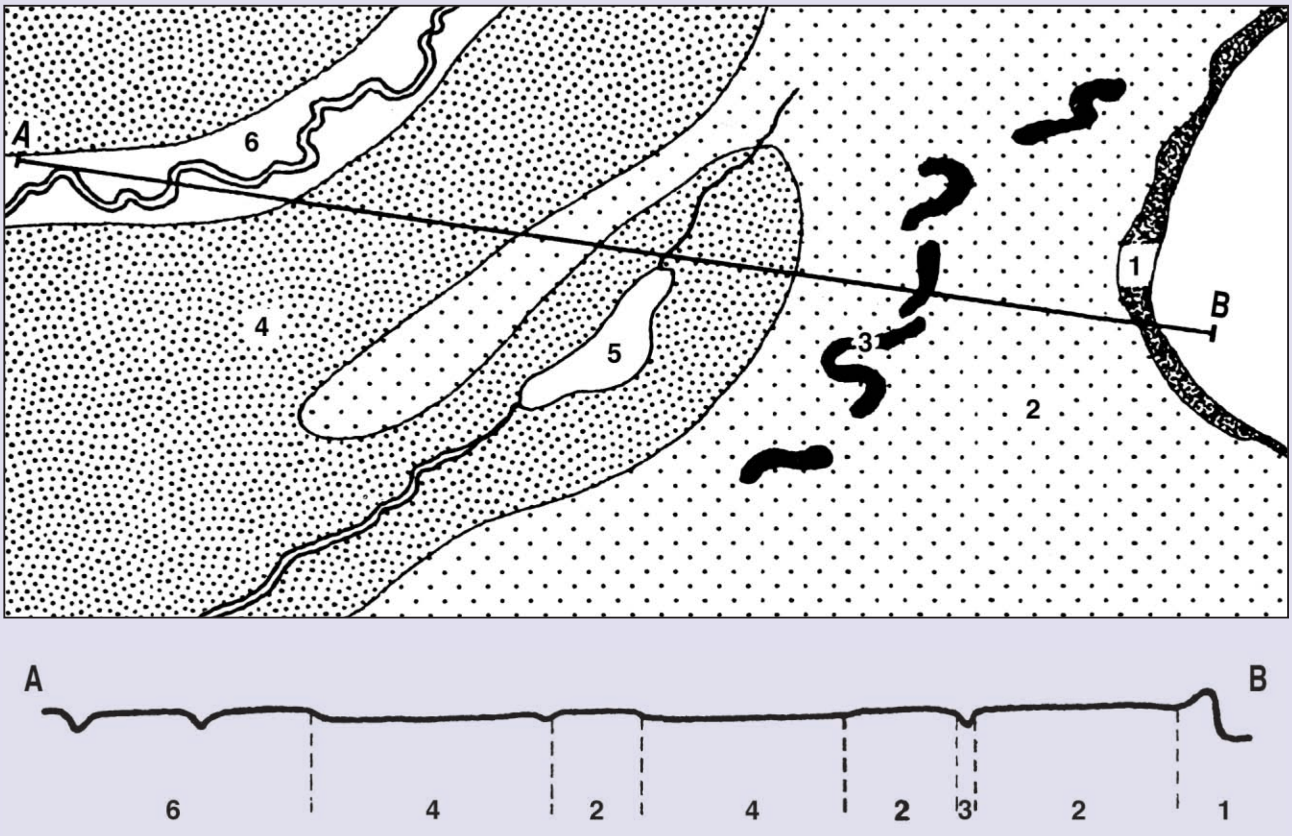
18 **Composite levee plains** (Figure 22). Stable depositional alluvial floodplains of very low relief consisting of a better drained central levee plain flanked by more extensive and typically very poorly drained back plains. The central levee plain consists of a channel with low sinuosity, bounded by continuous levee banks. The levee banks are long, low, wedge-shaped deposits of coarse material that form narrow continuous ridges on channel banks and slope gently away from the stream. They are built up by overbank flow at the level reached by frequent floods, and are generally better drained than the surrounding back plains. Levee banks frequently prevent water freely draining from the back plains after flooding or seasonal inundation.



1 River channel, slightly sinuous
2. Continuous low wedge shaped levee banks sloping gently away from channel
3. Scrolls, point bars
4. Back plain with very poor unchannelled drainage

Figure 22: The lower Fly River forms a stable floodplain consisting of a single channel and bordering levees. The levees are low and wedge shaped, sloping gently away from the channel and correspond to the darker-toned open forest flanking the river channel. Behind the levees are extensive blocked valley swamps covered in swamp woodland, grassland and herbaceous swamp vegetation.

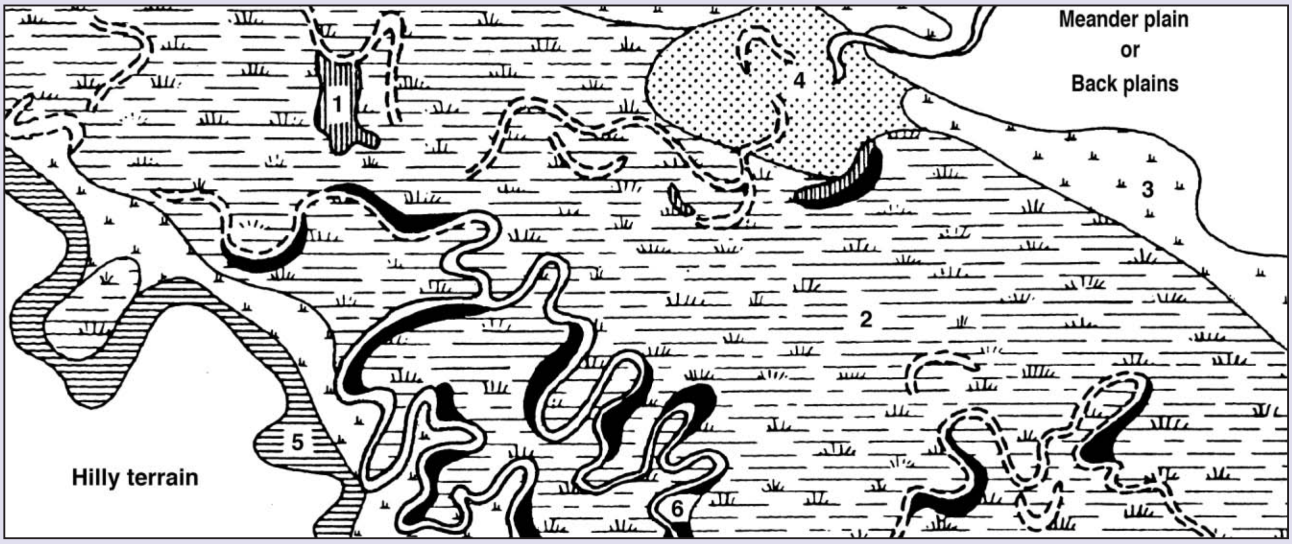
21 **Back plains** (Figure 23). Low lying floodplains formed of fine alluvial sediments and characterized by poor drainage with small lakes and swamps and prior stream channels frequently present. Back plains are generally lower than their associated meander plains and levee plains, and thus subject to prolonged inundation during high water levels. As most of the suspended load of the river is deposited on the levees and scrolls bordering the central channel, deposited on back plains is largely fine silt, clay and/or peat accumulation.



1. Levee banks of large river
2. Higher alluvial back plains
3. Prior levee banks bordering discontinuous prior channels
4. Lower alluvial back plains
5. Permanent shallow swamps
6. Alluvial plain of small stream

Figure 23: Back plain near Lohiki (Gulf Province) with old meander cut-off covered in swamp grassland and better drained flat to slightly undulating plain covered in dense open forest.

22 **Back swamps** (Figure 24). Extensive marshy semi-permanently to permanently inundated depressed areas of floodplains with drainage impounded or impeded by a central levee or meander plain, or on the coast by beach ridges. Small lakes and swampy prior river channels may be included. These freshwater swamps are maintained wherever land gradients and drainage outlets are inadequate to disperse the rain and run-on water. Deposition from suspended sediments of rivers includes fine silt, clay and/or peat accumulation. The depth of standing water and duration and depth of flooding on this landform type is highly variable throughout PNG and depends entirely on local conditions. However, the water table remains above ground level throughout the year irrespective of the flood regime of the central floodplain.



1. Small permanent lakes in old cut-off meanders
2. Extensive permanent floodplain swamps including local low levees, scrolls and swales; deeply flooded in wet season, with water table permanently above ground level
3. Extensive shallower floodplain swamps, flooded in wet season with water table permanently at/or above ground level, slightly higher-lying than unit 2 (above)
4. Drainage intake areas, permanently or seasonally with shallow water Gently sloping swamp margins, seasonally inundated
5. Discontinuous higher levee and floodplain scrolls, associated with active through-going or abandoned river channels

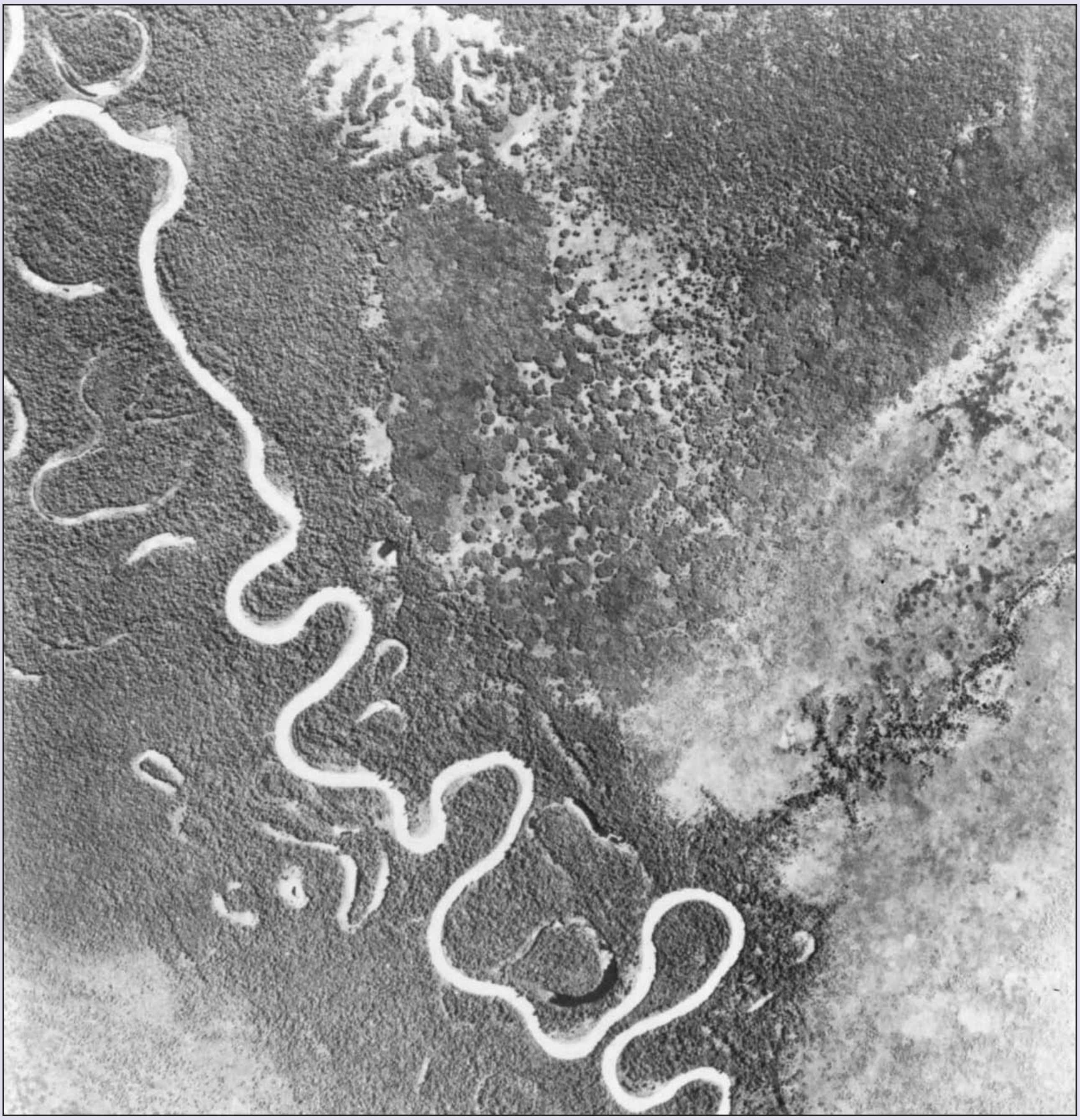
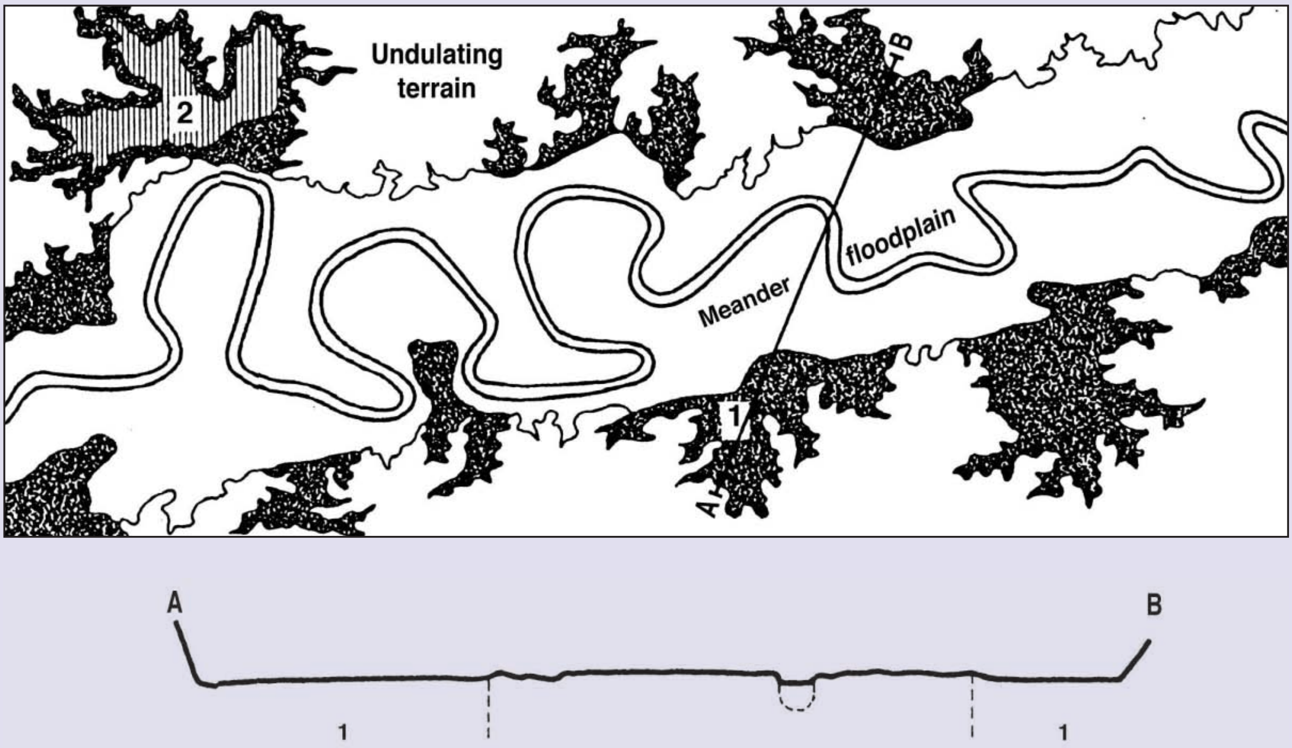


Figure 24: The meander floodplain of the Torii River (Gulf Province) with meander cut-offs and scroll complexes is flanked with extensive permanent back swamps (right). Vegetation changes reflect variation in the depth and duration of inundation within the back swamp from the deepest permanent swamp with mixed herbaceous swamp vegetation (bottom right, lighter toned) through swamp woodland of predominantly sago palm (centre right) to the shallowest semi-permanent swamp with open forest on the margins adjacent to hills in the north (top).

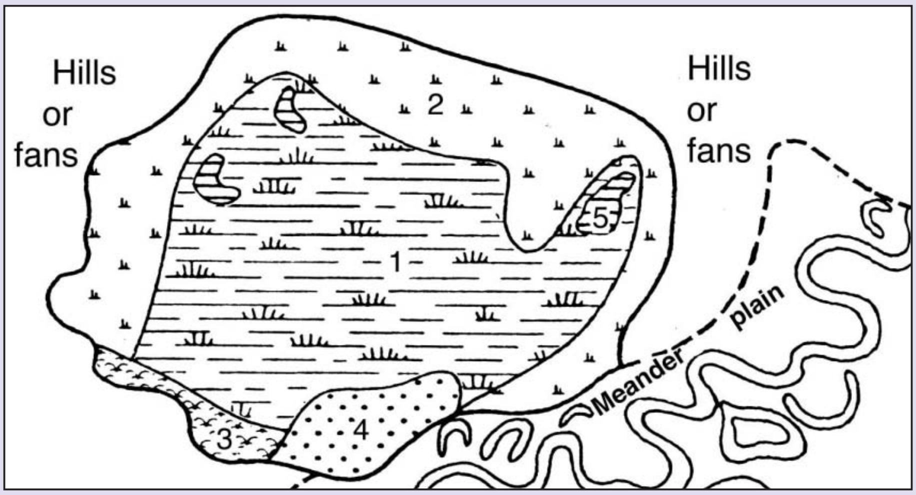
23 Blocked or drowned valley swamps and lakes and their associated swampy floodplain (Figure 25). Swamps and small lakes and their associated floodplains, in smaller tributary valleys, that have been drowned or blocked when relatively more rapid sedimentation along the main stream cuts off the tributaries at their outlet. These swamps are slightly lower than the adjacent meander plain and are inundated for most of the year. The blocked valley swamps and lakes are connected to the major rivers by narrow and highly sinuous channels through which water flows either from the tributary valley into the major river or vice versa, depending on where the water level happens to be higher. Consequently when the major river is in flood they overflow into the blocked valley swamps, while at low water they receive water from them.



1. Swamps in valley blocked by alluvial lobes deposited by major rivers; inundated in wet season
2. Permanent lakes and irregular open water channels

Figure 25: Blocked valley swamp, north-west of Weam (Western Province) with herbaceous swamp vegetation and swamp grassland surrounded by dry evergreen forest.

24 **Undifferentiated swamps** (Figure 26). All seasonal or permanent swamps that cannot be classified as either back swamps or blocked valley swamps. Many of these swamps occur in karst areas where they occupy basins without drainage or with poor internal drainage, and where the water table is either seasonally or permanently at or above the ground surface level.



1. Permanent swamp
2. Semi-permanent swamp, occasionally drying out
3. Waterlogged margins
4. Seasonally inundated swampy margins
5. Lakes

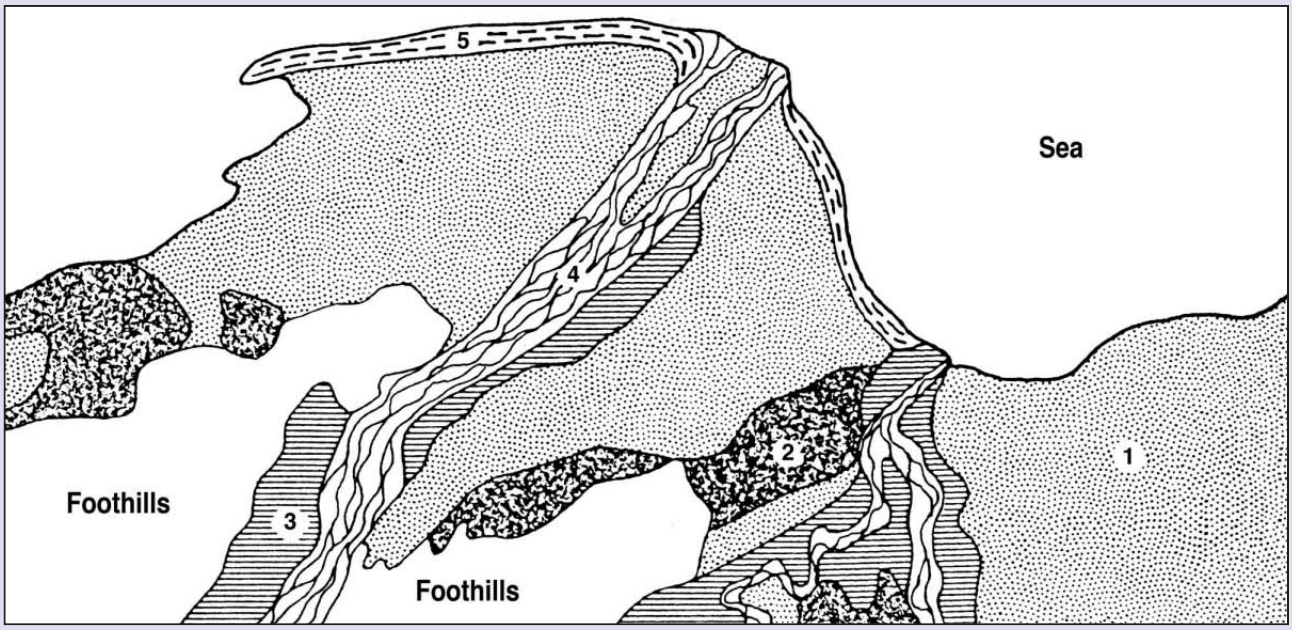
Figure 26: Undifferentiated swamps with extensive swamp forest of Melaleuca and Nauclea and tall grassland. The wetter areas, including oxbows, have herbaceous vegetation.

25 **Braided floodplains or bar plains** (Figure 27). Unstable depositional floodplains characterized by a rapidly migrating network of shallow anastomosing channels, separated by gravel, sand, silt and mud bars. The channels are broad but shallow with steep gradients, low sinuosity and un-navigable by even small craft. Steep channel gradients transport large quantities of sediment during flood. They are generally associated with the formation of alluvial fans in tectonically active regions, and subject to frequent flooding and active aggradation and erosion by channeled stream flow.

Figure 27: The braided floodplain of the Markham River (near Kaiapit) is characterized by a highly unstable anastomosing network of shallow interconnecting channels separated by migrating coarse textured gravel, sand and silt bars.

2.7.6.4 Recent fans

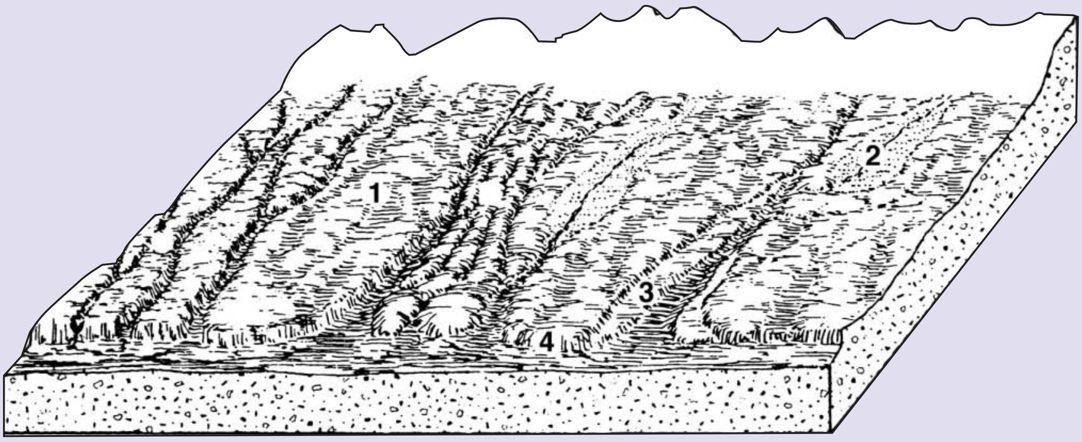
26 **Composite bar plain and alluvial fan complex** (Figure 28). Active unstable alluvial floodplains consisting of a bar plain and an associated active alluvial fan. The bar plain consists of ridge-like bars separated by numerous rapidly migrating broad, shallow interconnected channels of low sinuosity and steep gradient. The ridge-like bars consist of accumulations of gravel, sand, silt, and mud, the sediments generally being coarser than the channel sediments. The alluvial fans are typically conical in shape radiating downslope from the point where the stream leaves the mountain, composed of coarse sediments, and are built up by braided channels with steep gradients.

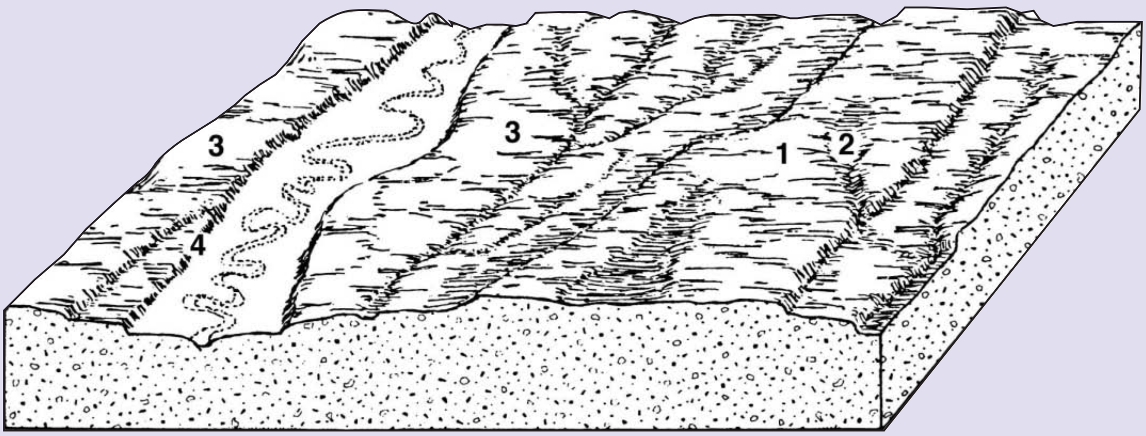


1. Flat or gently undulating alluvial surface
2. Flat or gently sloping higher fan remnants
3. River terraces occassionally flooded
4. Gravelly, braided channel tracts
5. Beach rige complex

Figure 28: Composite bar plains and fans along the Rai coast, Madang Province. Two active alluvial fans with their associated unstable braided bar plains form a gently sloping coastal plain subject to flooding during the wet season.

29 **Little dissected recent alluvial fans** (Figure 29). Little dissected relatively recent alluvial fans of largely fluvial origin consisting predominantly of stratified older sediments of unsorted gravel, boulders and finer layers. They are above the present flood level and generally unweathered, relatively incoherent and subject to rapid channeling and slope collapse. The individual fans are typically conical in shape radiating downslope from the apex where the stream leaves the mountain, but frequently coalescing to form a largely continuous sloping main surface. The main surfaces are variably incised, the incision generally being greatest near the apex and decreasing gradually downstream until the main fan surface merges with the active parts of the fans. A brained floodplain and two or three well developed terraces are usually present on each individual fan. The development of the fans is associated with tectonically active mountain areas, with entrenchment of fan streams at the apex, alluvial terrace formation and active fan development varying greatly from fan to fan and frequently taking place simultaneously.





1. Level or gently undulating fan surfaces traversed by unchannelled drainage depressions
2. Shallow drainage depression
3. Flat terrace surface above present flood plains
4. Steep escarpments, frequently gullied, along margins and dissecting streams

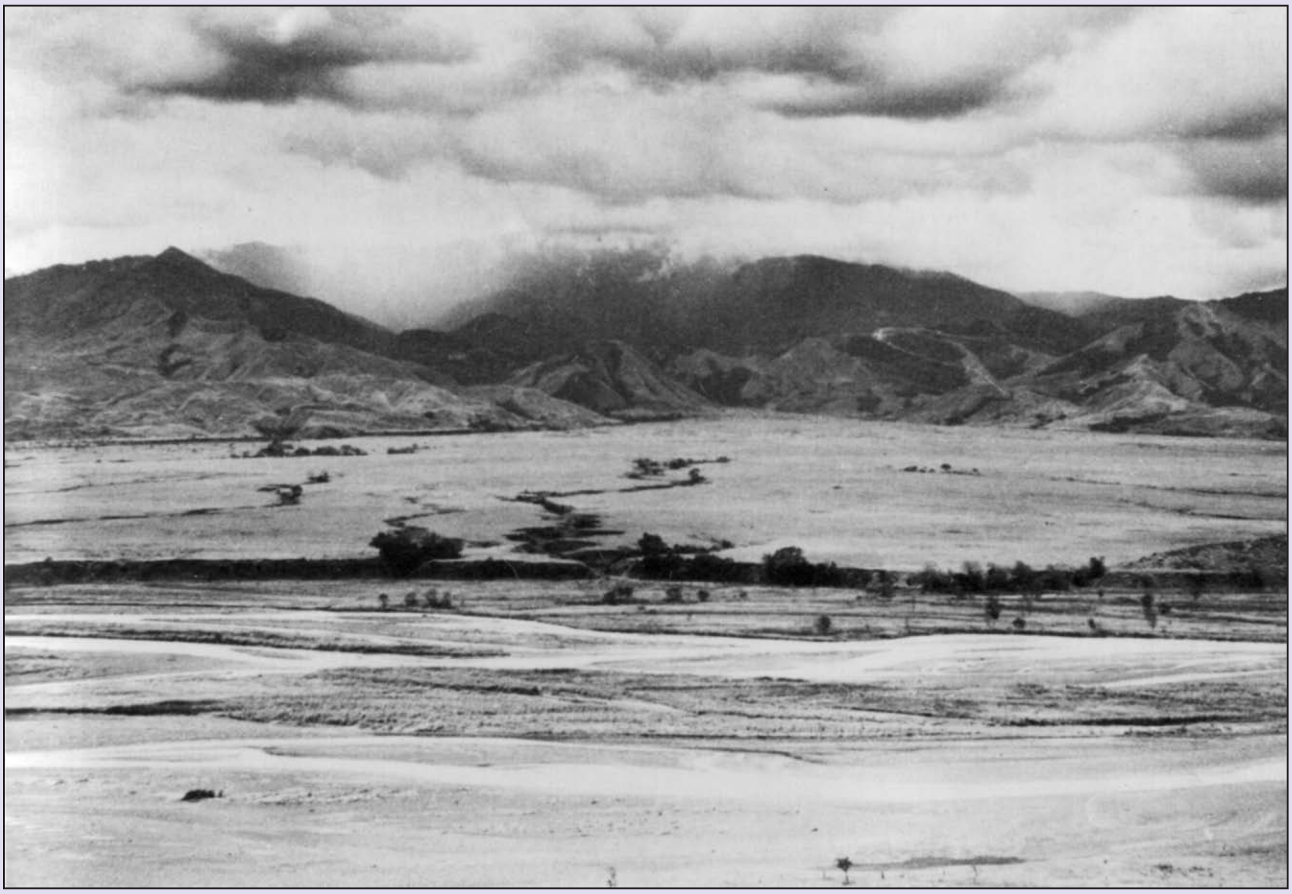


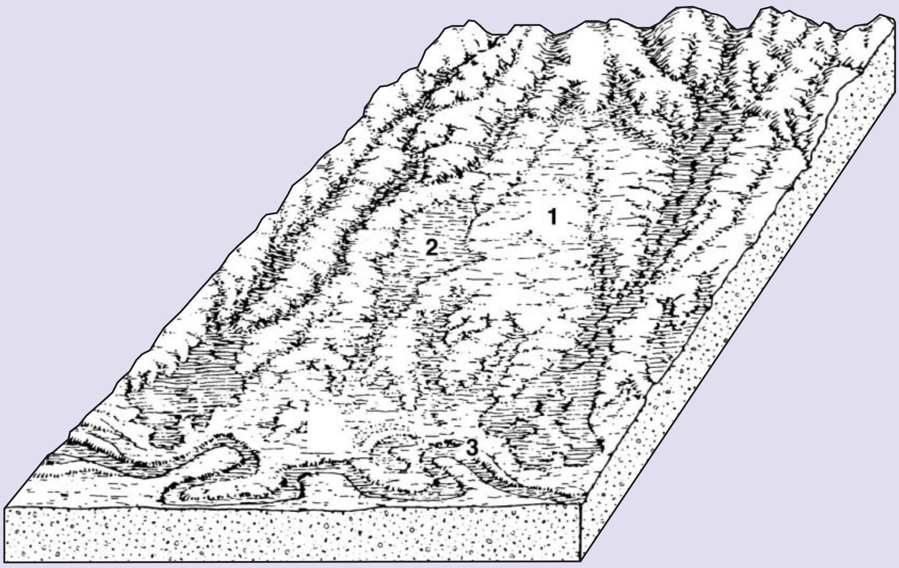
Figure 29: Little dissected recent alluvial fan forming a gently sloping surface extending from the forest-cleared foothills and lower slopes of the higher misted Finnisterre Ranges to the braided stream bed of the Ramu River (in foreground) which truncates the fan surface.

2.7.6.5 Relict fans

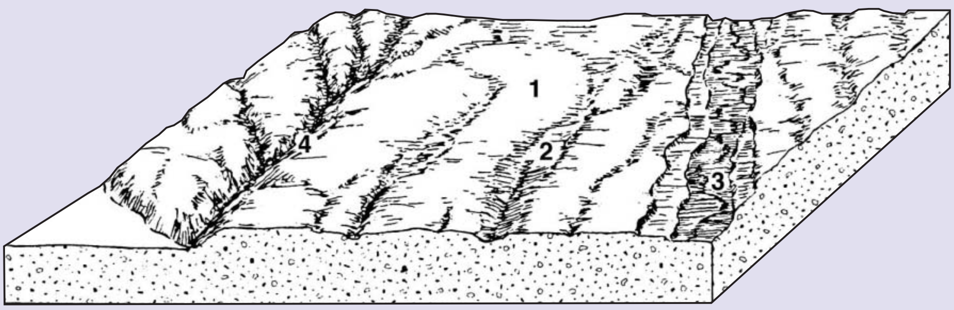
30 Little dissected or undissected relict alluvial, colluvial and mudflow fans (Figure 30, Figure 31). Strongly weathered level to undulating, undissected to partly dissected relict alluvial fans and their associated terraces that occur above the present flood level of major streams and are no longer subject to active depositional processes. They may take two different forms:

1. Extensive continuous sloping surfaces of coalescing fans, the development of which is largely associates with tectonic and/or seismic activity.
2. Much smaller in extent and of local occurrence, and associated with intermontane basins or some other form of foreland that acts as a local sediment storage.

The fan surfaces generally slope up to 2º and contain shallow unchannelled poorly drained or swampy drainage depressions. Steeper slopes are associated with either widely spaced through-going streams or dissecting minor streams entrenched below the depositional surface with floodplains and terraces present. The fans have been built up by two main processes, fluvial deposition and mudflow activity. Their surfaces are currently being subjected to fluvial erosion with active fan formation having ceased or being very localized and on a small scale.



Sepik fans

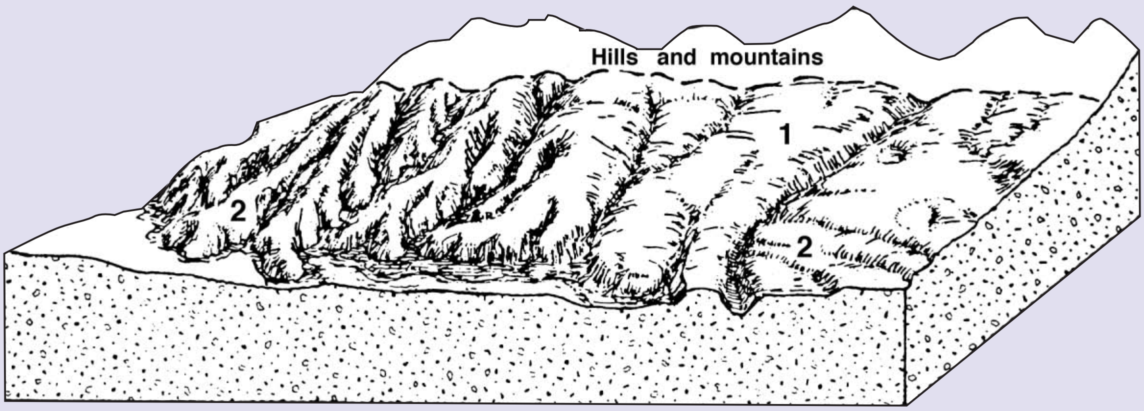


Highlands fans

1. Flat to gently undulating fan surfaces
2. Shallow drainage depression
3. Floodplains and discontinuous narrow terraces
4. Very steep slopes, frequently gullied, along margins and dissecting streams

Figure 30: Gently undulating little dissected lower relict fans of the Sepik area (East Sepik Province). These extensive fans are of fluvial origin and the sediments are predominantly very fine grained, largely clay and silt, but locally sand and quartz gravel are interbedded. Except for the quartz, the sediments are strongly and deeply weathered, and soils are similarly weathered with maturely developed profiles. Owing to human agricultural activity and burning practices the original hill forest has largely been replaced by mid-height grassland (foreground) except along the drainage lines.

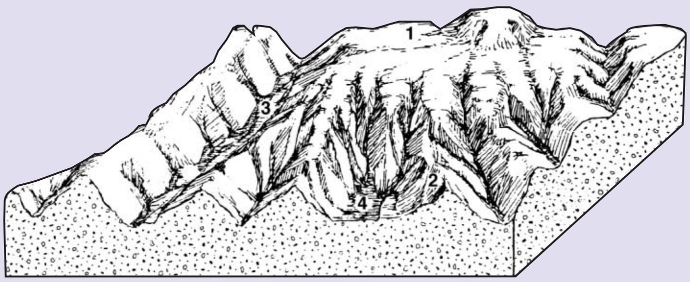
Figure 31: Little dissected relict alluvial fan surfaces formed near Minj in the intermontane basin of the Waghi Valley (Western Highlands Province). Small remnant fan surfaces grade radially into flat-crested spurs, and narrow-steep sided ridges covered with remnant and secondary forest. The composite meander plain of the Waghi River is incised into the fan surface forming discontinuous terraces.



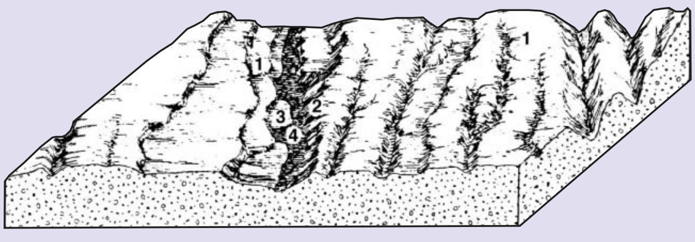
Lowland mudflow fans

31 Dissected relict alluvial, colluvial and mudflow fans (Figure 32, Figure 33, Figure 34). Strongly weathered and moderately to strongly dissected relict alluvial fans and their associated terraces that are above the present flood level of dissecting streams and no longer subject to active depositional processes. They either form a continuous sloping surface of coalescing fans, the development of which is associated with tectonic and/or seismic activity, or are much smaller in extent and of local occurrence, occurring in association with intermontane basins or some other form of foreland that acts as a local sediment storage. The fan surfaces are currently being subjected to fluvial erosion and mass movement with active fan development having ceased or being very localized and on a small scale. Narrow floodplains and terraces may be present along through-going streams. The surfaces are variably dissected and may take a number of different forms:

- Small strongly dissected remnant fan surfaces that grade radially into flat-crested spurs and narrow steep-sided ridges (e.g. Waghi fans near Minj in the Western Highlands Province and Goroka fans in Eastern Highlands Province).
- Flat to gently undulating terraced fan surfaces separated by steps, and closely and steeply dissected along margins (e.g. Asaro River fans near Goroka, Eastern Highlands Province).
- Terraced alluvial valley fills and associated colluvial fans deeply dissected by narrow streams (e.g. Lai and Tschak valleys near Wabag and Wapenamanda, Enga Province).
- Accordant flat-topped low ridges with prominent secondary slumping and associated mudflow activity (see upper parts of Sepik fans illustrated in block diagram for landform type 30).
- Strongly weathered hummocky mudflow fans variably dissected to form steep narrow ridges or hummocky surfaces, with deep secondary mass movements (mostly slumps) common (e.g. Musa basin and Kokoda areas of Northern Province).

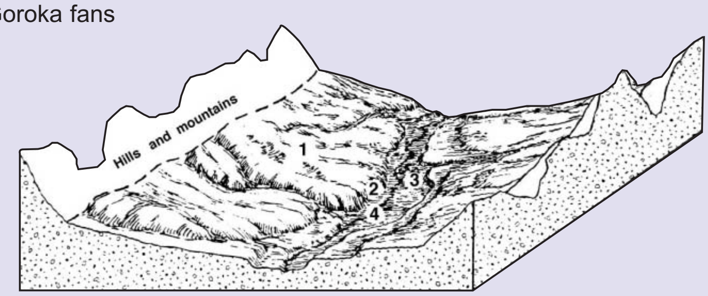


Waghi fans



Goroka fans

1. Flat to gently undulating fan surfaces, generally strongly weathered
2. Dissected fan surfaces
3. Narrow, level to gently sloping, discontinuous terraces
4. Floodplains



Wabag fans

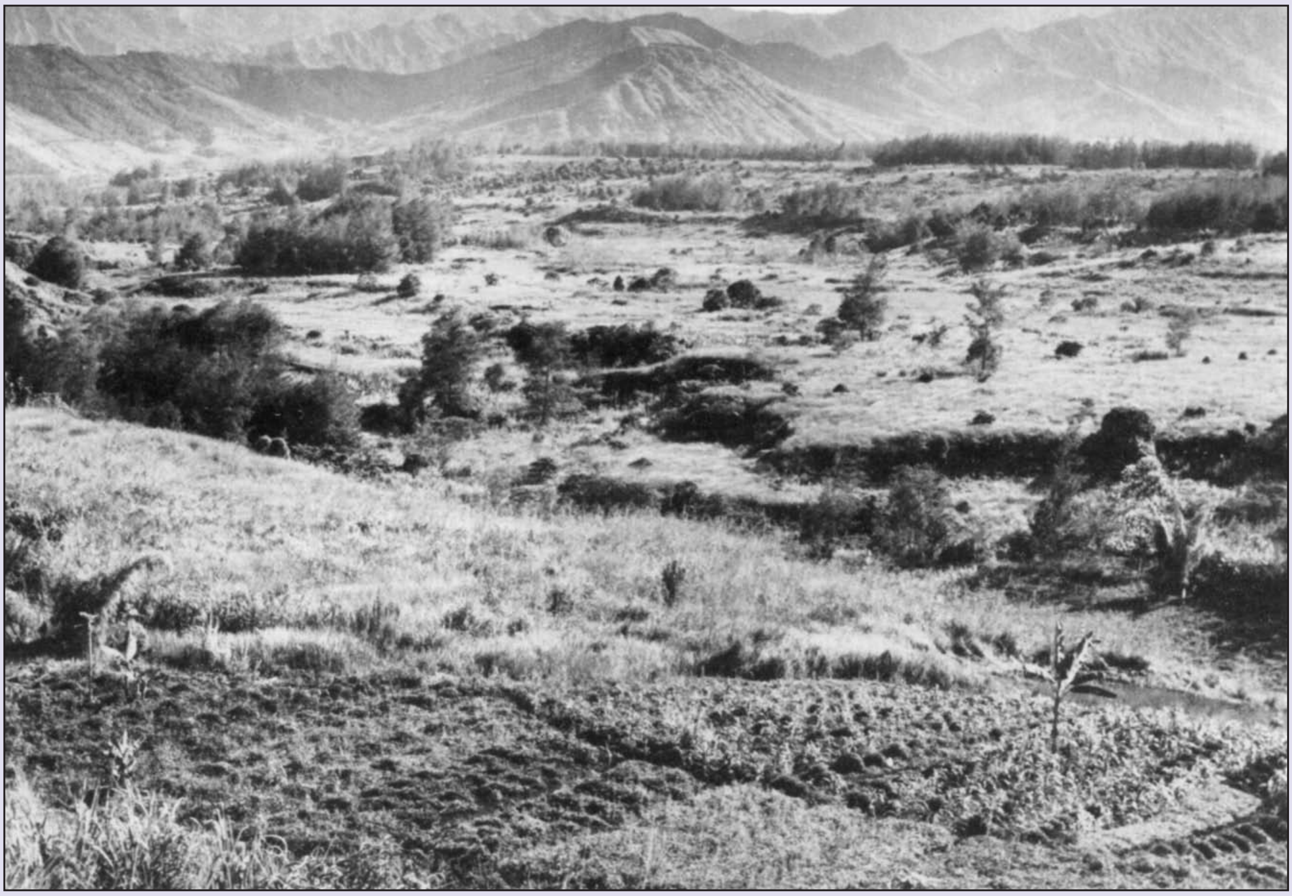


Figure 32: Strongly dissected relict alluvial fans in Asaro valley with two well-developed terraces, Casuarina plantings and native gardens in the foreground.

Figure 33: Dissected older and higher parts of the relict fan surfaces in the Sepik area (West Sepik Province). The former fan surface is represented by accordant ridges. Slumping and associated mudflow activity are very prominent in these poorly consolidated sediments covered with mid-height grassland with remnants of lowland hill forest in the valleys and sago in the understorey.

Figure 34: Extensive debris flow, mudflow and fluvial fans in the Musa basin, forming several generations of fans. The older mudflow and debris fans (dark toned) are being dissected and subjected to secondary mass movements, mostly in the form of slumping, and consist mainly of unsorted coarse rock debris in a clay to silt matrix. Recent fluvial fans (bottom) have a more regular smoothly sloping surface and consist of stratified deposits, largely gravel, sand and silt.

2.7.7 Landforms of fluvial erosion and mass movement

2.7.7.1 Introduction

Landforms of fluvial erosion and mass movement are formed by a variety of distinctly different processes, and are consequently a more heterogeneous group than other landform groups. In this database they are subdivided according to:

1. morphological form (i.e. structural surfaces of mountains and hills);
2. degree of surface expression of structural control.

On this basis, two types of structural surfaces (landform types 43 and 45), and five types of mountains and hills (landform types 50, 51, 52, 53, 54) are differentiated (Table 11). There are few, if any, landforms in PNG which are not controlled by rock or tectonic structure to some extent (i.e. by bedrock structures, such as bedding planes and foliation, or by fault and/or joint control). The degree to which this structure is expressed topographically, however, varies greatly. Landforms of fluvial erosion and mass movement with prominent structural control are those landforms where such structure has had a marked influence on shape (i.e. structural plateau, sloping structural surfaces, homiclinal ridges and cuestas, and strike ridges and hogbacks). The great majority of structurally controlled landforms in PNG reflect bedrock structures such as planes of bedding and foliation formed in a variety of tectonic settings.

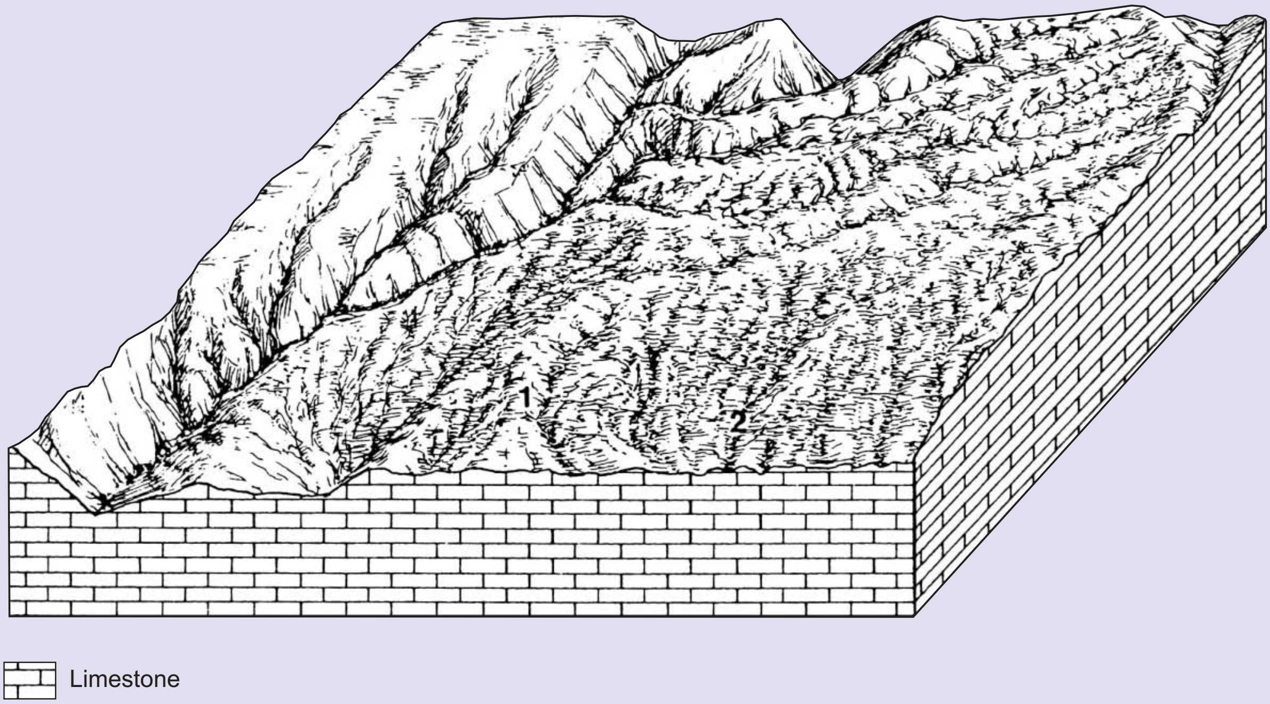
2.7.7.2 Structural surfaces

Structural surfaces refer to landforms of fluvial erosion and mass movement that form extensive surfaces largely controlled by the underlying bedrock structure.

43 **Structural plateaux** (Figure 35). Extensive elevated irregular surfaces with relatively flat summit areas formed on flat lying or gently sloping rocks, commonly bounded on one or more sides by escarpments and subject to severe erosion along the margins. They formed on relatively resistant rock, such as limestone and sandstone, and are essentially the product of differential erosion and uplift. Plateaux on limestone are intensively modified by karst erosion and the surface may be pitted with dolines, that is, small circular to oval closed depressions eroded by solution (e.g. Mueller Ranges, Southern Highlands Province) or rounded hills may rise above the general level of the highly irregular plateau (e.g. Sarawaged Ranges, Morobe Province).

Figure 35: In the eastern summit areas of the Sarawaged Ranges of the Huon Peninsula (Morobe Province), a thick sequence of flat to gently dipping limestone beds form an irregular plateau surface. The surface is bounded in the south by a near vertical cliff (bottom left) several hundred metres high, but dipping at an angle of 15^o to the north, and its extent is being reduced by vigorous headward erosion from the edges of the plateau. This aerial photograph shows a formerly glaciated part of the plateau covered in grassland (lighter toned), and a small part of the larger structural plateau covered with forest and pitted with dolines (darker toned). The dolines tend to occur preferentially along smaller drainage lines many of which have consequently become inactive.

45 **Finely dissected sloping erosional surface with structural control** (Figure 36). Sloping plateaux of very low relief with irregular surfaces whose summits form a well defined plane that slopes consistently in one direction. Sloping erosional surfaces are essentially landforms transitional between homoclinal ridges (or hogbacks) and plateaux. However, the slope of the plane of accordance of the summit surface is not simply an exposed rock surface. They are relict surfaces formed on relatively resistant rock and are essentially the product of different erosion and uplift. Erosional processes have exploited the naturally occurring weaknesses in the rock such as bedding planes and fault planes (e.g. on Huon peninsula) or planes of foliation (e.g. the Dayman Dome, Northern Province).



1. Intricately dissected low irregular ridges with accordant summit levels
2. Drainage pattern exploitting natural weakness of the rock, bedding planes, fault planes or planes of foliation

Figure 36: The Dayman Dome (Northern Province) in the foreground is a finely dissected sloping structural surface formed on densely foliated metamorphics (schist). Erosional processes have exploited the naturally occurring weaknesses in the schist, so that the dome surface is parallel to the planes of foliation of the rock. The surface has been finely dissected with the summit levels forming well defined planes that slope consistently in one direction (north-east). In the background the massive ridges on metamorphic and basic volcanic rocks of the Owen Stanley Ranges with deep steep sided V-shaped valleys, are sharply contrasted with the much lower and more finely dissected hills and ridges on poorly consolidated sedimentary rocks to the east (left centre) of the Gwoira Range.

2.7.7.3 Mountains and hills

Mountains and hills are landforms of fluvial erosion and mass movement which are subdivided in the database on the basis of the degree of structural control and relief (Table 6).

Mountains and hills with weak or no structural control (landform types 50, 51, and 52) take a variety of forms and exhibit great differences in drainage density, dissection pattern, slope form, slope steepness, relief, crest pattern and slope symmetry. The dominant factors determining these attributes are rock type and tectonic structure in response to weathering and erosional processes.

The dominant factors determining the surface expression or form of mountains and hills with prominent structural control (landform types 53 and 54) are the relative resistances to weathering and erosion of the various rock types present and the steepness and dip of the bedrock strata.

The distinction in the database between hilly terrain with weak or no structural control (landform code 50) and mountains and hills with weak or no structural control (landform code 51) is based solely on relief, the former having relief of less than 100m, the latter greater than 100m. Descriptions of these two landform types are provided in this handbook for different rock types. It should be noted that these descriptions are generalities which apply to relatively homogenous rock types covering large areas. However, the landform patterns are much more complex if different rock types are closely interbedded, if intense fracturing by tectonism has occurred, and if layers of superficial deposits, such as ash, cover the original bedrock.

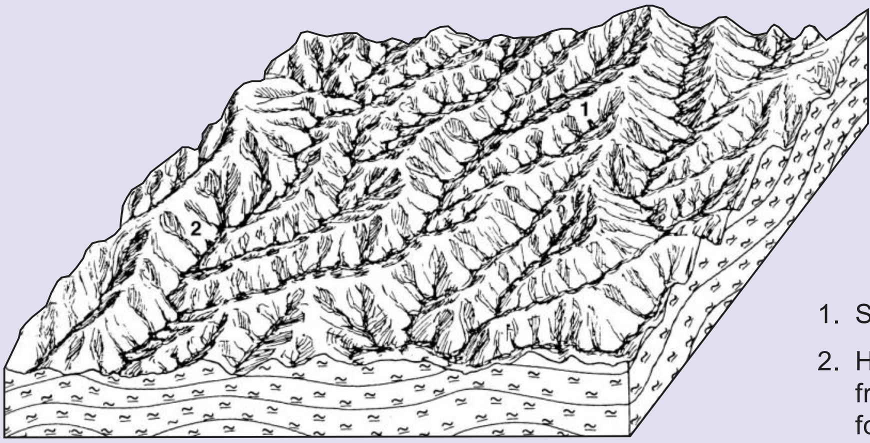
50 **Hilly terrain with weak or no structural control** (Figure 37, Figure 38). Dissected hills of low relief (less than 100m) with weak or no structural control and with steep slopes, and sharp crests separated by narrow incised V-shaped valleys. Broadly, mountains and hills or hilly terrain on igneous rocks are of massive appearance, with a coarse dissection pattern and steep rather straight slopes. On metamorphic rocks slopes are more irregular, but ridges are still massive and straight in the overall slope profile. On sedimentary rocks these landforms have great variability due to differences in composition, degree of induration, bedding, homogeneity within the layers, and degree of tectonic deformation.

Figure 37: Finely dissected hills on coarse sedimentary rocks (mainly conglomerate, sandstone, siltstone) in the Musa basin (Northern Province) with straight slopes, shallow soils and an intricate vegetation pattern of Eucalypt savannah and mixed deciduous lowland hill forest.

Figure 38: Sharp crested ridges with densely dissected slopes on fine grained sedimentary rocks west of Madang. The irregular vegetation pattern is due to the practice of shifting cultivation. Villages are on top of the narrow ridge crests.

51 **Mountains and hills with little or no structural control** (Figure 39, Figure 40, Figure 41, Figure 42, Figure 43, Figure 44, Figure 45). Mountains and hills of high to very high relief (greater than 100m) with weak or no structural control, steep escarpments and narrow sharp crested ridges separated by V-shaped valleys with steep river gradients.

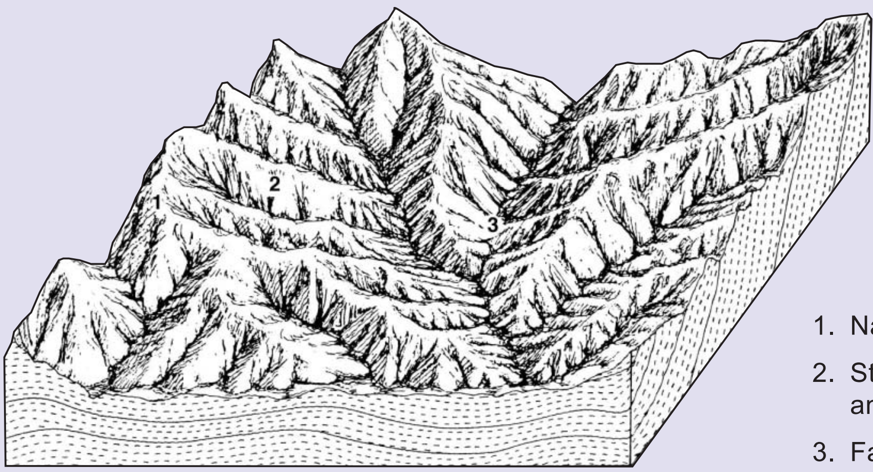
Mountains and hills with weak or no structural control on soft fine grained sedimentary rocks (Figure 38) such as marl, mudstone and siltstone. They are characterized by a very dense dissection pattern and highly irregular slopes with great variability in slope steepness because of frequent slumping and intense gullying. Slopes can vary from 50º at slump headwalls to a few degrees at slump toes. Weathering is mostly shallow and immature.



1. Sharp crested ridges
2. Highly irregular slopes with frequent slumping and gullying forming steep slopes

Marl and mudstone

Mountains and hills with weak or no structural control on consolidated fine grained sedimentary rocks (Figure 38) have more uniform slopes and a coarser dissection pattern than on soft fine grained sedimentary rocks. Slopes are usually steep and partly influenced by rock structure, and valleys are V-shaped. Slumping is important and debris slides common particularly in areas of thinly laminated but relatively hard mudstones and shales.

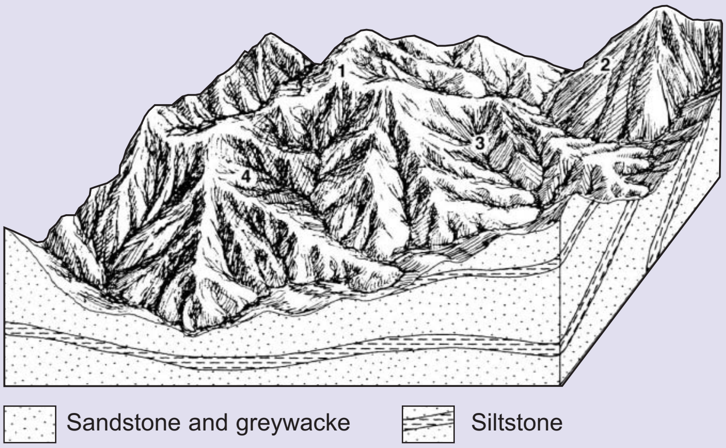


1. Narrow sharp crested ridges
2. Steep slopes subject to slumping and debris slides
3. Fairly coarse dissection pattern

Shale

***Figure 39:** Mountains and hills on massive indurated shale and siltstone in Simbu valley (Simbu Province) with V-shaped valleys, steep (40°) straight side slopes which, in spite of intensive use, have maintained a surprising stability.*

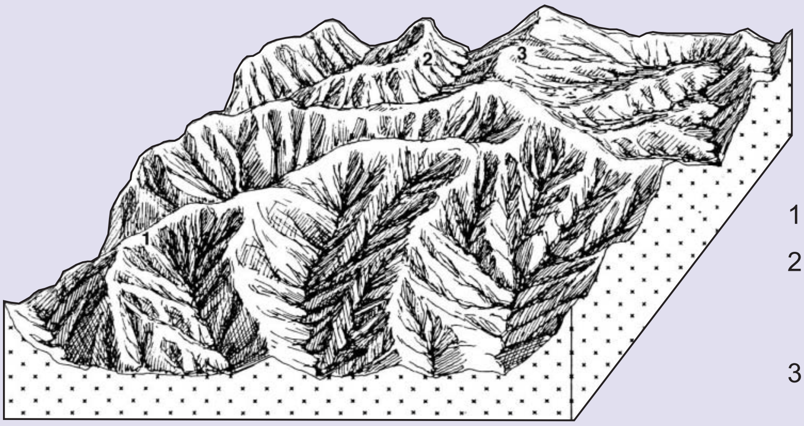
Mountains and hills with weak or no structural control on coarse grained sedimentary rocks (Figure 40) such as greywacke sandstone and conglomerate, show great variability of form. Young poorly consolidated rocks form a dense intricately dissected pattern of sharp narrow ridges with steep sided V-shaped valleys, while more indurated and older rocks form coarser patterns with uniform slopes.



1. Massive high ridges on indurated coarse grained sedimentary rocks
2. Steep fairly uniform slopes
3. Coarse dissection pattern
4. Large deep seated slumps common

Figure 40: The dense intricately dissected ridges of the Gwoira Ranges formed on conglomerate and poorly sorted sandstone and siltstone contrast sharply with the more coarsely dissected massive ridges on the edge of the Owen Stanley Ranges formed on metamorphosed basalt, dolerite and gabbro. Little dissected terraced fans formed of stony alluvial sediments (mostly gravel and sand) occur at the foot of the Owen Stanley Ranges.

Mountains and hills with weak or no structural control on acid igneous rocks, basic igneous rock and basic volcanics (Figure 41, Figure 42) generally are massive in appearance with sharp ridge crests, straight rather uniform slopes of 35 to 45º, and a coarse dissection pattern. Rivers and streams are cut in bedrock but loaded with coarse well-rounded gravel. Landslides of the debris avalanche type are common. The block diagram below is of rugged mountains and hills on massive igneous rocks (predominantly granodiorite) with shallow weathering.



1. Sharp ridge crest
2. Steep straight slopes, usually 35 to 45º with landslides, in particular debris avalanches, common
3. Massive hills and mountains shallowly weathered

Granodiorite

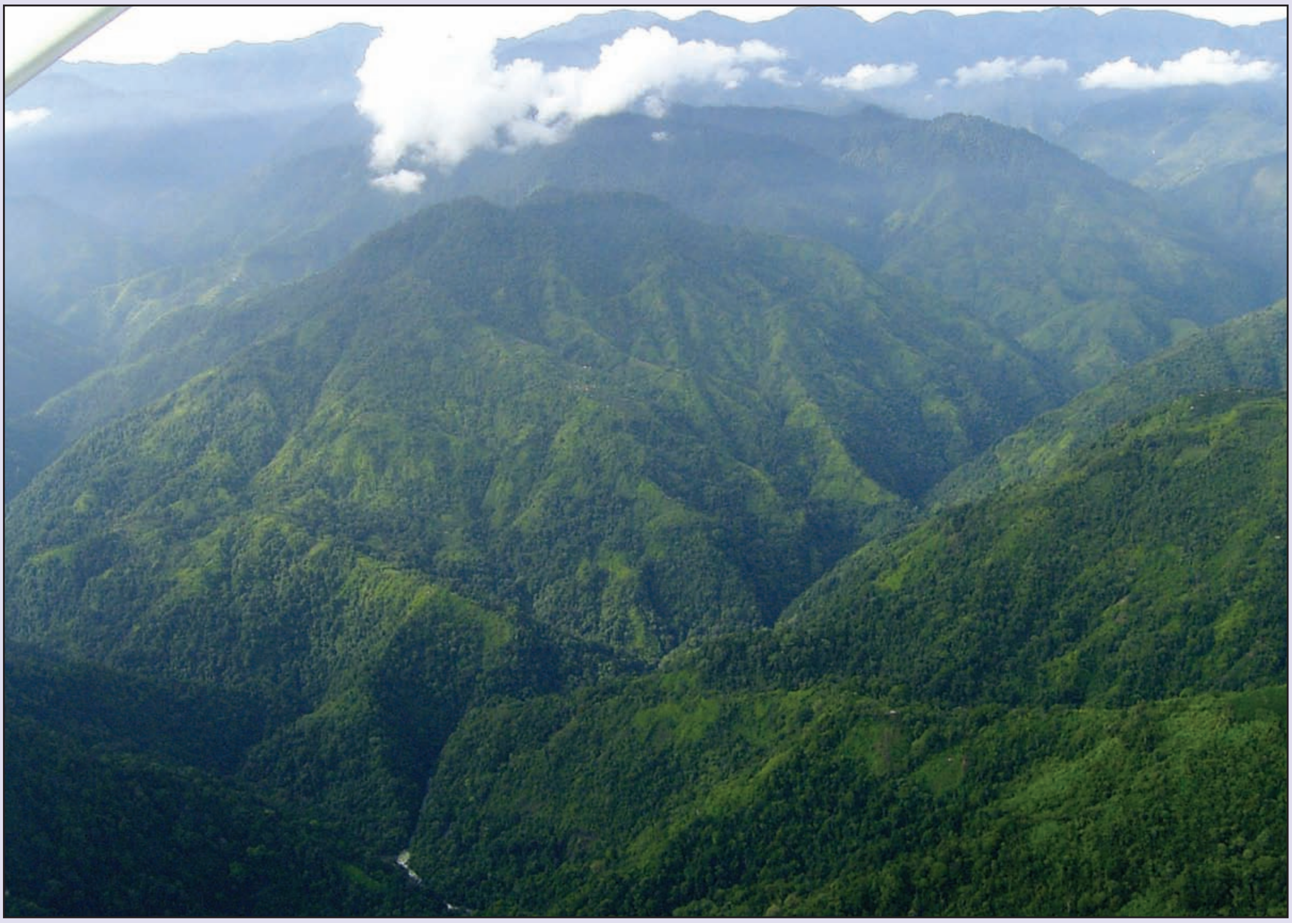
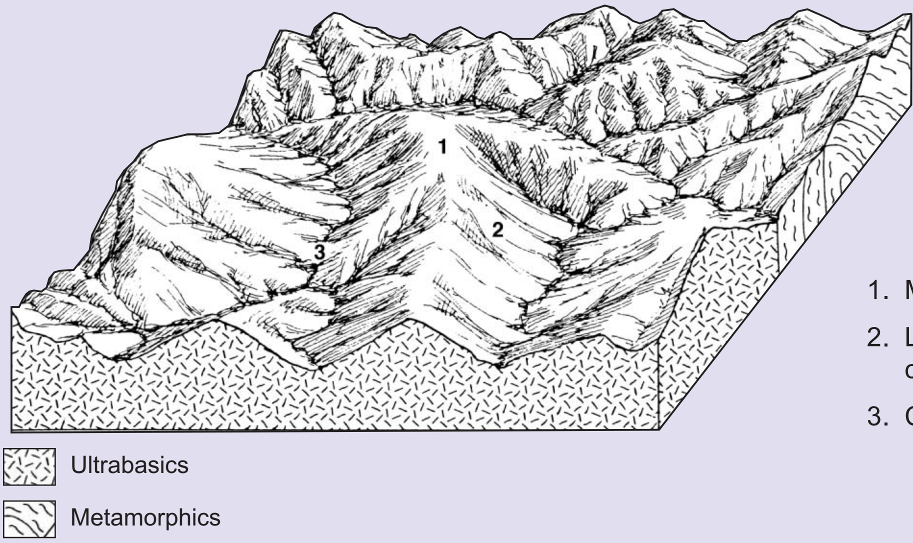


Figure 41: Mountains and hills on basic to intermediate volcanic rocks with very high relief, and very steep slopes in the Upper Gusap valley of the Finnisterre Ranges at about 2000m. Vegetation is predominantly regrowth and gardens, with some remnant forest in the gullies.

Figure 42: Hilly mountainous terrain with short sharp ridges on basic igneous rocks near Bisianumu, on the northern edge of the Sogeri plateau (Central Province) with crowned lowland hill forest (in valleys) and Eucalypt savannah (on ridges).

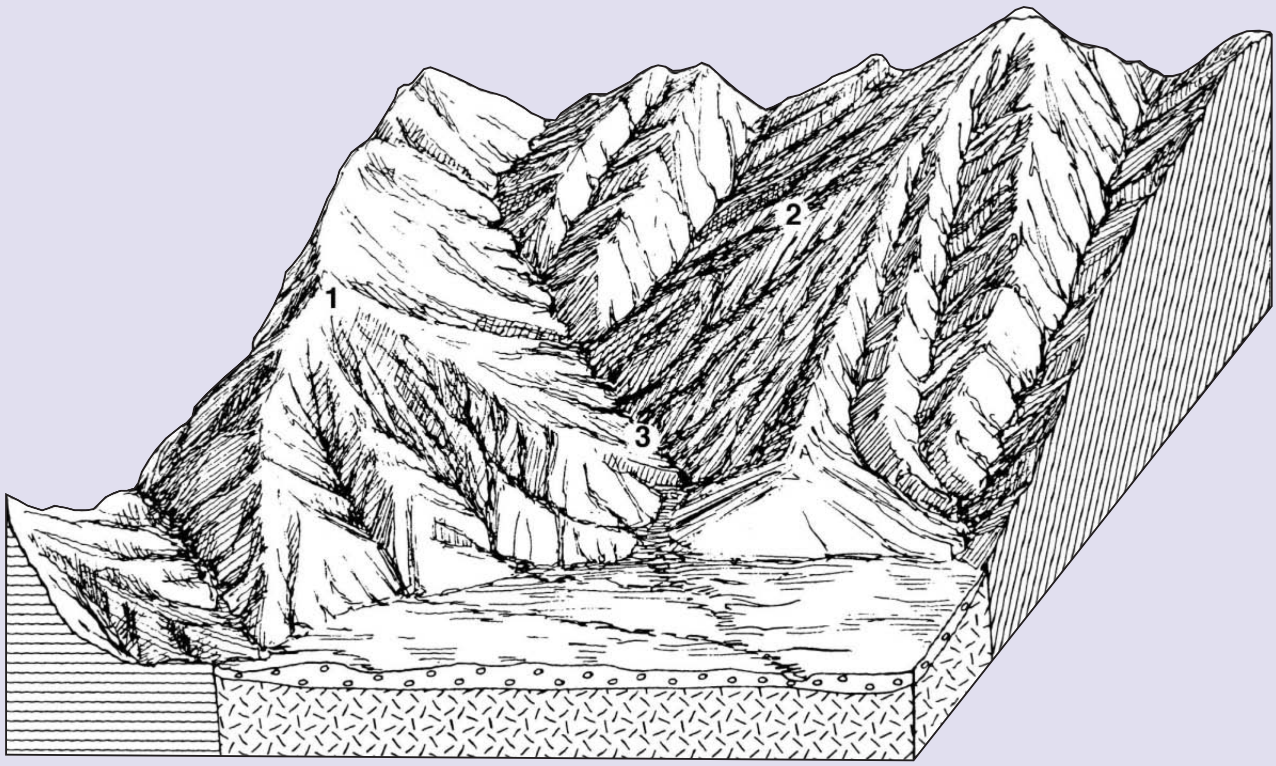
Mountains and Hills on ultrabasic rocks with weak or no structural control (Figure 43) form massive ridges with long straight, slightly convex slopes and a coarse dissection pattern. Stream incision is generally shallow in the upper slopes, and shallow saucer-shaped depressions and definite V-shaped valleys form only on lower slopes.



1. Massive ridges
2. Long steep straight or slightly convex slopes
3. Coarse dissection pattern

Figure 43: Massive ridges with very steep relatively uniform side slopes and narrow crests on ultrabasic rocks in the ranges south-east of Salamaua (Morobe Province).

Mountains and hills on metamorphic rocks with no structural control (Figure 44) consist of massive ridges with straight slopes in the overall profile but which in detail are irregular and dissected by a close network of small streams and gullies that frequently follow foliation planes. Weathering is very shallow and the soil profile consists of coarse colluvium overlying the bedrock. However, on deeply weathered metamorphics the ridges are much lower in relief, crests are broad and slopes more gentle with a fine irregular dissection pattern.

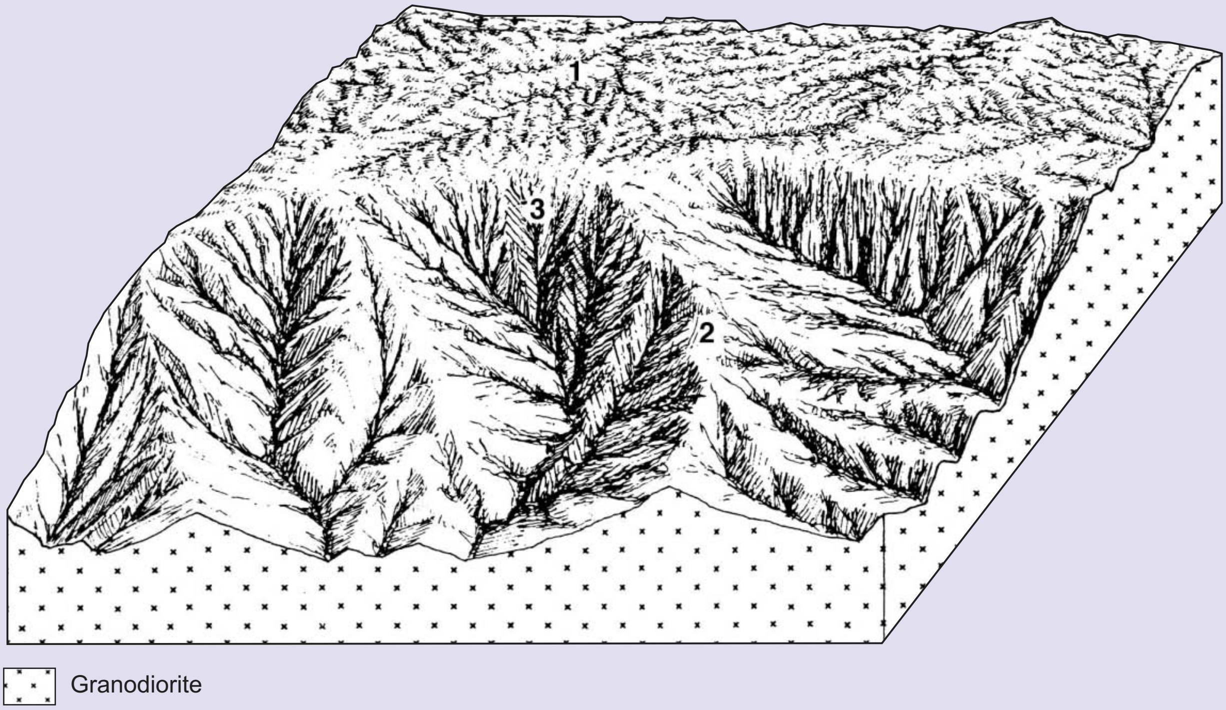


Unconsolidated fanglomerates   Schist   Ultrabasics

1. Massive mountains and hills, shallowly weathered, rock outcrops common
2. Long straight steep slopes
3. Dissection by dense network of small streams

Figure 44: The eastern part of the Owen Stanley Ranges is dominated by massive shallowly weathered mountains and hills developed on high grade metamorphic rocks with long straight slopes (centre foreground and right) and steeper sharper ridges of very high relief with landslides common formed on basic volcanic rocks (left background).

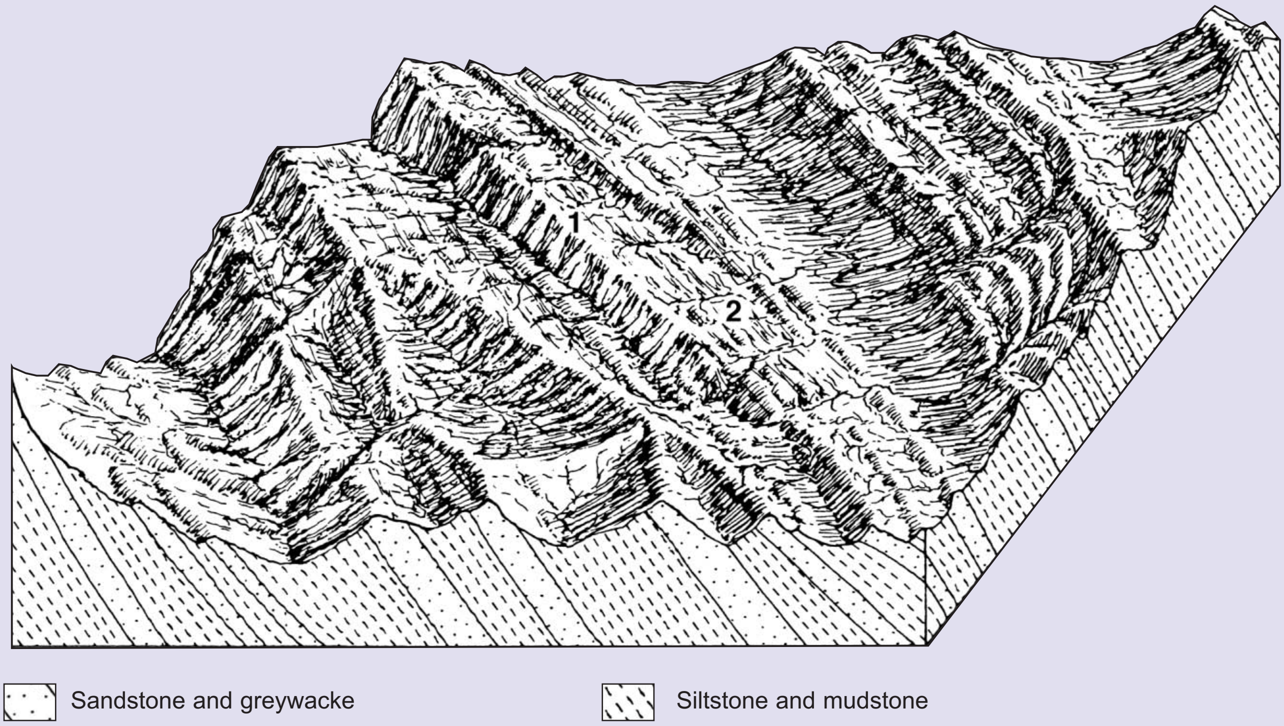
52 Mountains and hills associated with relict surfaces with weak or no structural control (Figure 45). Low sharp ridges with short steep slopes, a fine dissection pattern and characterized by lower relief, less steep river gradients and a more mature and thicker weathering profile than the surrounding landscape.



1. Finely dissected relict surfaces
2. More coarsely dissected younger hills and mountains
3. Steep scarps associated with transition from older relict surface to younger hills and mountains

Figure 45: Relict surface (foreground) in Owen Stanley Ranges formed on metamorphic rocks contrasts sharply with the surrounding distinctly higher relief and gradients of the mountains and hills formed on basic volcanic rocks (background).

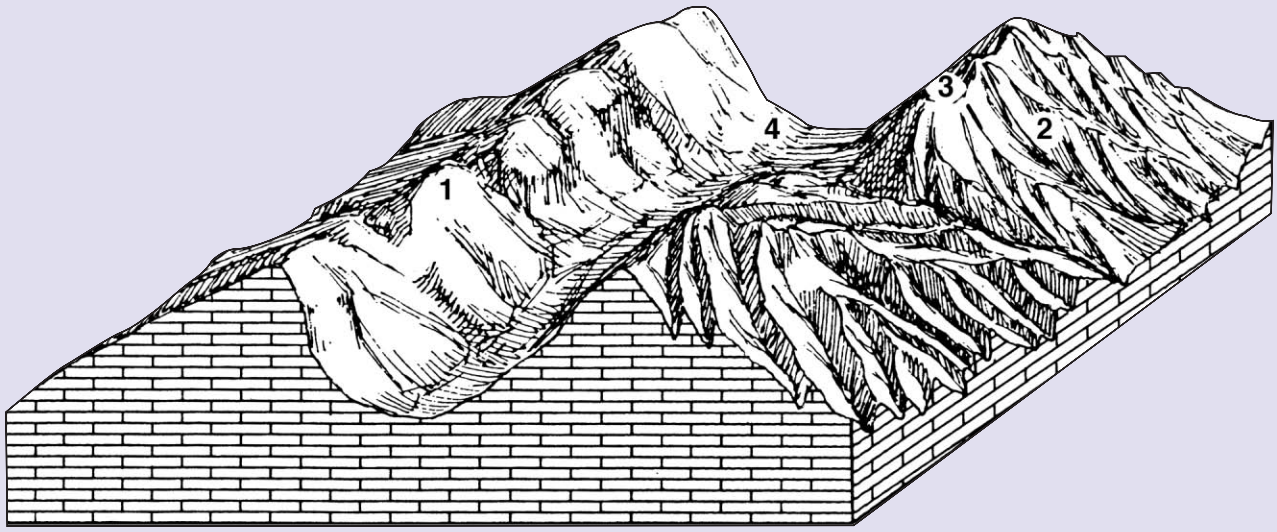
53 **Homoclinal ridges and cuestas** (Figure 46). Structurally controlled asymmetrical ridges with steep outcrop slopes and longer, more gentle dip slopes of less than 25º. They are developed where beds of varying resistance to weathering and denudation are present and have been brought into an inclined position by faulting or folding. Subsequent differential erosion causes the less resistant layers to erode more rapidly so that the rock structure of the more resistant layers is gradually given surface expression. They are best developed where limestone and hard porous sandstone form the resistant layers alternating with softer shales, mudstones and siltstones. Slopes are frequently irregular due to slumping and gullying. Homoclinal ridges have dipslopes of 10 to 25º, whereas cuestas generally have dipslopes less than 10º.



1. Sharp ridges and scarps formed on inclined layers of resistant rock
2. Gently inclined dipslopes of 10º to 25º for homoclinal ridges and less than 10º for cuestas formed on layers of less resistant rock

Figure 46: Rows of closely spaced homoclinal ridges, with south-west facing steep escarpments and more gently inclined north-east facing dipslopes in the Aure area, Gulf Province. Rock types are interbedded less resistant siltstone and mudstone with ridges and escarpments formed largely on more resistant sandstone, greywacke and minor limestone. Both the outcrop slopes or escarpment and the longer, more gentle displopes are intensely dissected by short steep gullies.

54 **Strike ridges and hogback ridges** (Figure 47). Sharp crested structurally controlled ridges with dipslopes greater than 25º formed on highly tilted resistant rock layers. They are developed where beds of varying resistance to weathering and denudation are present and have been brought into a strongly inclined position by faulting or folding. Subsequent differential erosion causes the less resistant layers to erode more rapidly so that the rock structure of the more resistant layers is gradually given surface expression. They are best developed where limestone and hard porous sandstone form the resistant layers alternating with softer shales, mudstone and siltstone.



1. Relatively short step outcrop slopes, generally over 35º, and frequently debris covered, but sometimes with bare precipitous surfaces
2. Longer less steep dipslopes but with slopes over 25º
3. Sharp ridge crests
4. Gentler colluvial aprons and acree slopes

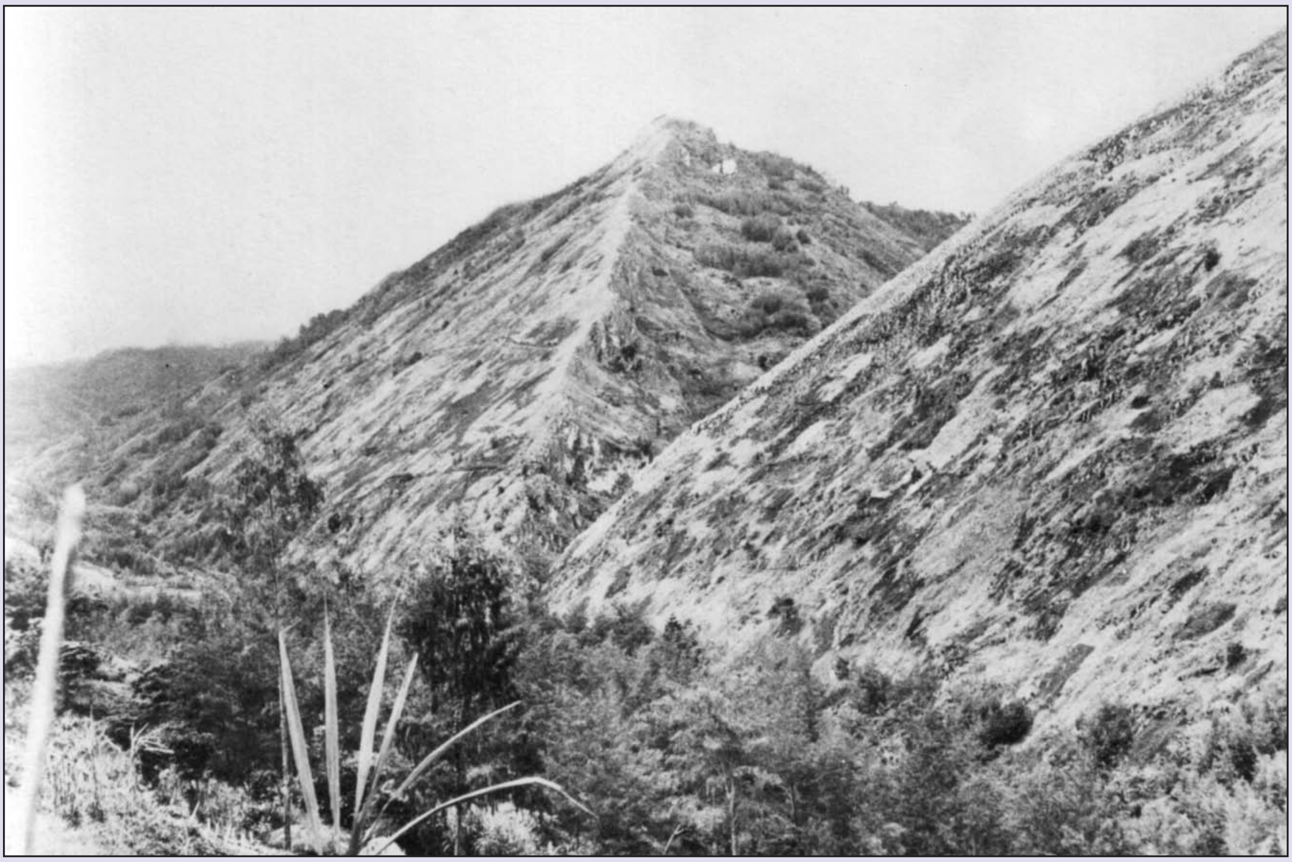


Figure 47: A striking feature of the Waghi – Mt Hagen area is the west-north-westerly trending Elimbari Ridge. It is a limestone hogback ridge with a south-westerly facing cliff scarp facing smooth steep (over 30º) dipslope. South of the ridge extensive coarse clastic material originating from the cliff forms a very hummocky landscape. The Simbu River has cut through the ridge in a deep V-shaped gorge. Intensive subsistence farming is found on the north-easterly facing dipslope.

2.7.8 Landforms of karst erosion

2.7.8.1 Introduction

Landforms of karst erosion refer to areas of limestone or dolomite with a unique type of topography in which solution by percolating groundwater and underground streams is the dominant process of landform development. Karst landforms are subdivided in the database on the basis of their morphological form into three landform types: karst plains, plateau with karst corridors and polygonal karst.

2.7.8.2 Karst plains

11 **Karst plains** (Figure 48). Flat to very gently undulating erosional plains of very low relief formed on limestone and developed largely by lateral solution and covered by a thin veneer of alluvium of variable thickness (mostly 1 to 2m) which may seal off the limestone surfaces. Low hemispherical hills rising from the plain, either individually or in small groups, may be included in this landform type.

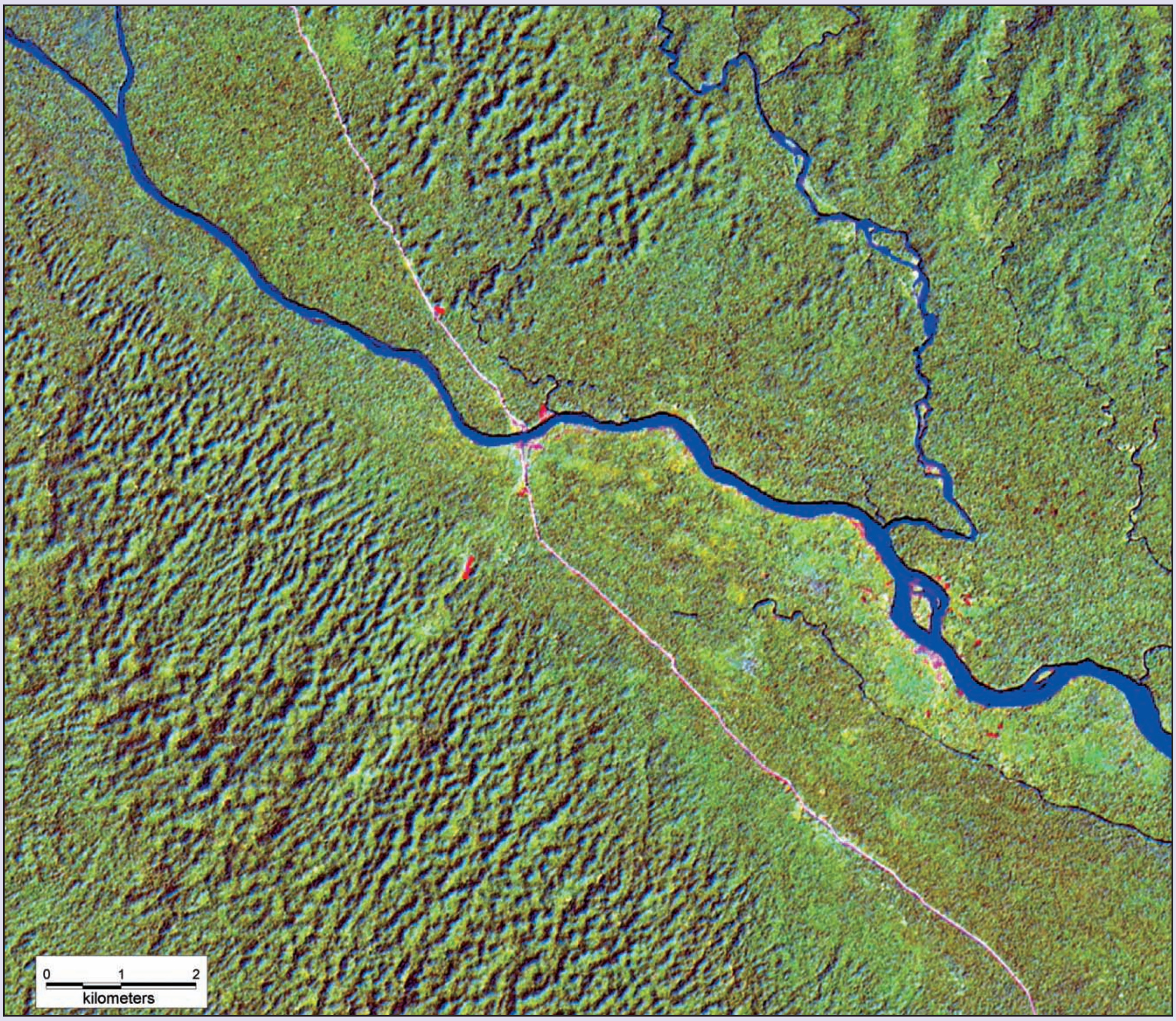
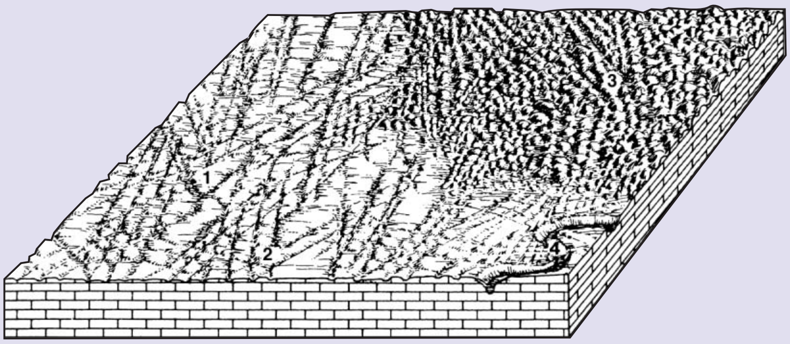


Figure 48: Satellite image showing the nearly flat karst plains adjacent to Pinini Creek near Kikori (Gulf Province). The plains extend laterally into polygonal karst hills that range from small low hummocks at the margin of the plain to larger hemispherical hills.

2.7.8.3 Karst plateau

42 Plateau with karst corridors (Figure 49). Elevated, flat topped limestone surfaces of very low relief with narrow, often discontinuous corridors cut in the limestone are eroded by solution along joints and faults and other lines of weakness, but without forming an integrated drainage network.



1. Flat topped to very gently sloping surface
2. Narrow discontinuous corridors cut in limestone preferentially along joints, faults and other lines of weakness
3. Cone karst consisting of conical or hemispherical hills with steep intervening depressions
4. Incised stream with steep slopes

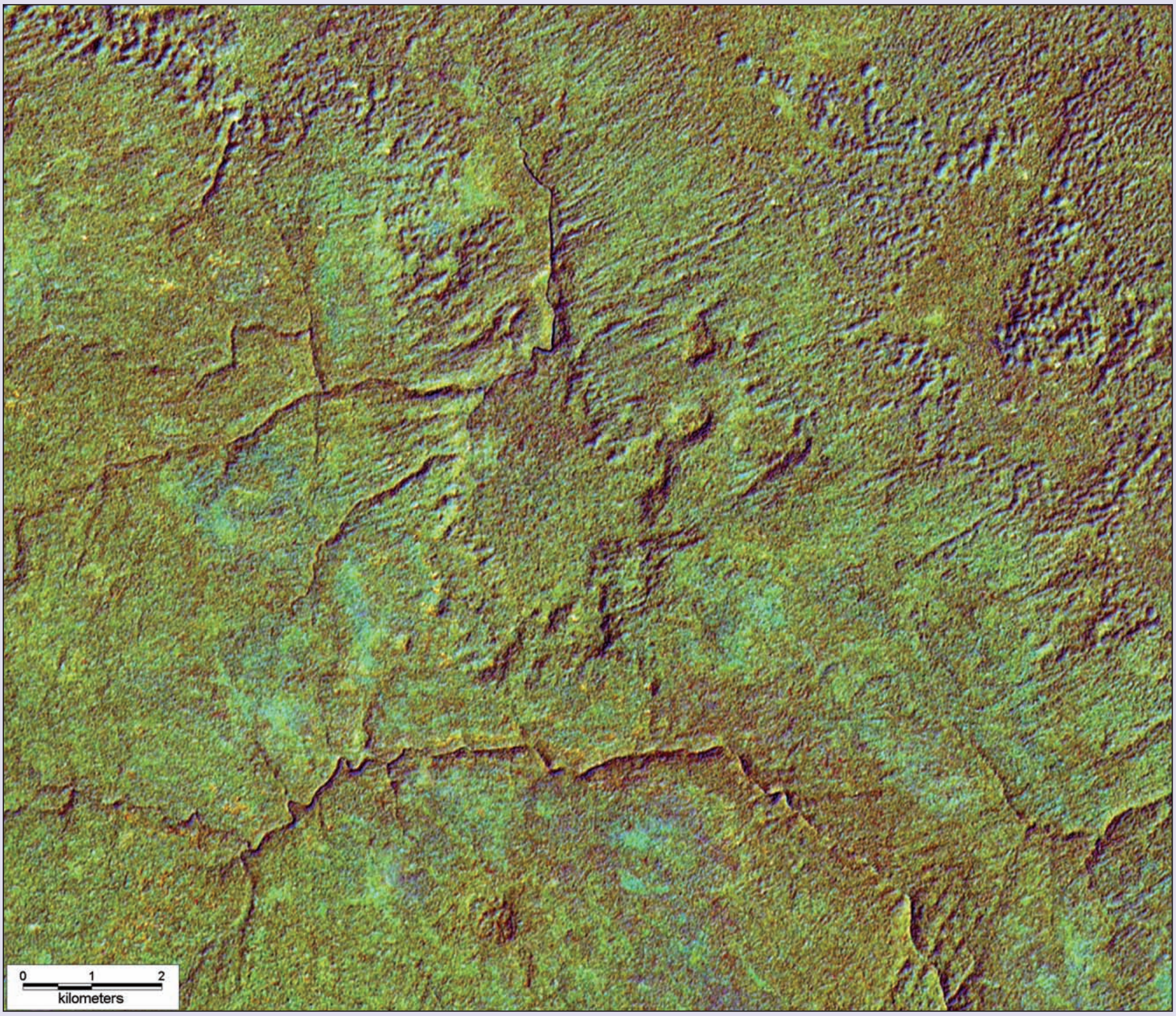


Figure 49: Satellite image of a plateau with karst corridors north-west of Kikori known as the Darai Plateau. Narrow corridors are cut into the limestone preferentially along joints and faults but no integrated drainage network has been developed in the north and west and a gradual transition to polygonal karst can be observed in the north-east.

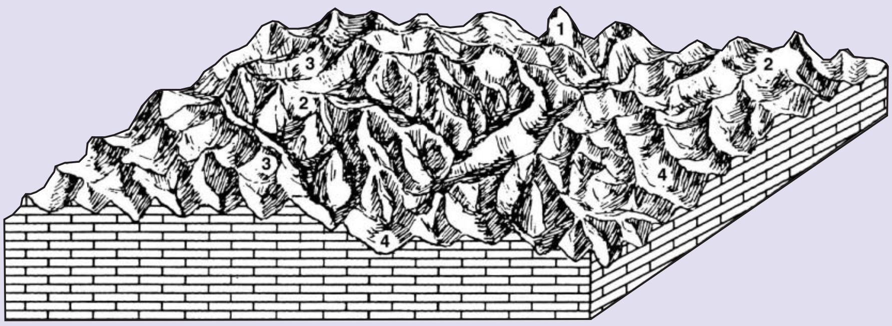
55 2.7.8.4 Karst mountains and hills

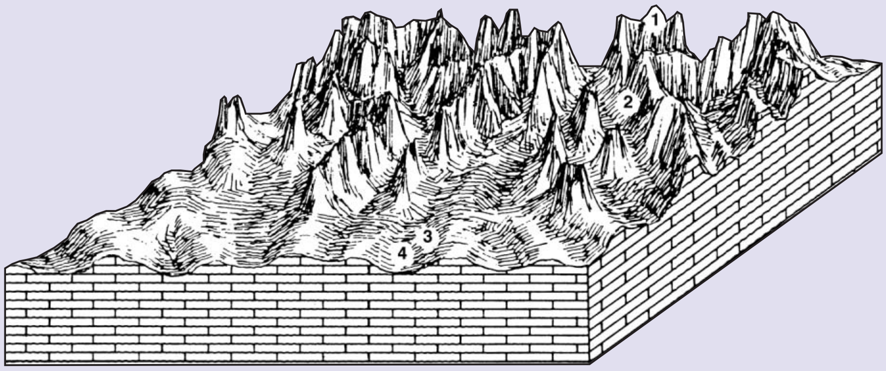
Polygonal Karst (Figure 50, Figure 51). Rugged limestone ridges or plateaux with great variability in form but all characterized by:

- a central depression or sink surrounded by a crudely polygonal shaped catchment or topographic divide;
- the absence, or poor development, of an integrated surface drainage network;
- erosion by continuously active solution by rain, surface water and ground water.

Polygonal karst is formed over limestone, dolomite and other soluble rocks as a result of differential solution of these materials and associated processes of subsurface drainage, cave formation, subsidence and collapse. The variable forms of karst include:

- steep sided pyramid hills with bowl shaped depressions (pyramid and doline karst);
- conical or hemispherical hills with steep intervening depressions (cone karst);
- steep conical or cylindrical hills with rounded tops enclosing deep depressions (tower karst);
- bare, nearly vertical limestone ridges with razorblade-like crests surrounding enclosed depressions (arête and doline karst);
- undulating surfaces incised by close set depressions with gully-like channels leading to roughly central stream sinks.





1. Very steep tower spires and rocky cliffs
2. Steep hill slopes with rock outcrop and debris cover
3. Slopes of enclosed depressions
4. Floors of enclosed depressions

Figure 50: Doline karst near Pamburai forming an undulating surface that is intensively gardened.

Figure 51: Arete and doline karst on Mt Kaijende east of Porgera comprising bare, nearly vertical, limestone ridges with razorblade-like crests surrounding enclosed depressions.

2.7.9 Volcanic landforms

2.7.9.1 Introduction

The distribution of active, dormant and extinct volcanoes in PNG is shown in (Figure 52). Volcanoes classified as active refer to volcanoes with direct observations of eruptions and which are reported in written records. Dormant volcanoes refer to volcanoes with either especially youthful morphological features, or notable active (or recently active) fumaroles and solfataras, volcanoes mentioned in indigenous stories or legends of eruptions, and recorded observations of events that may have been eruptions. Johnson (1979) notes that the criteria used in distinguishing extinct and dormant volcanoes are not clear cut, and to some extent arbitrary.

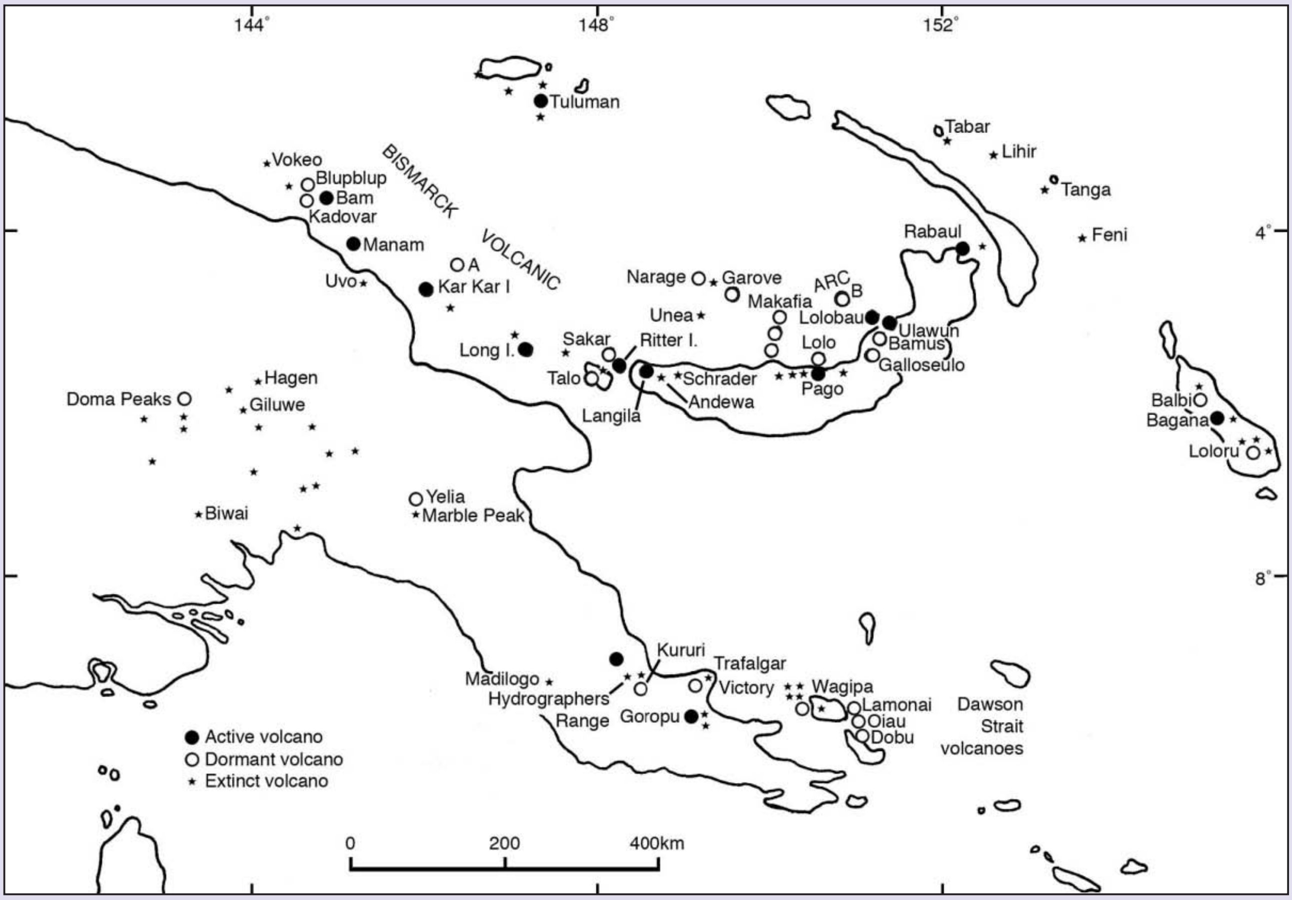


Figure 52: Distribution of eruptive centres in Papua New Guinea (adapted from Johnson, 1979).

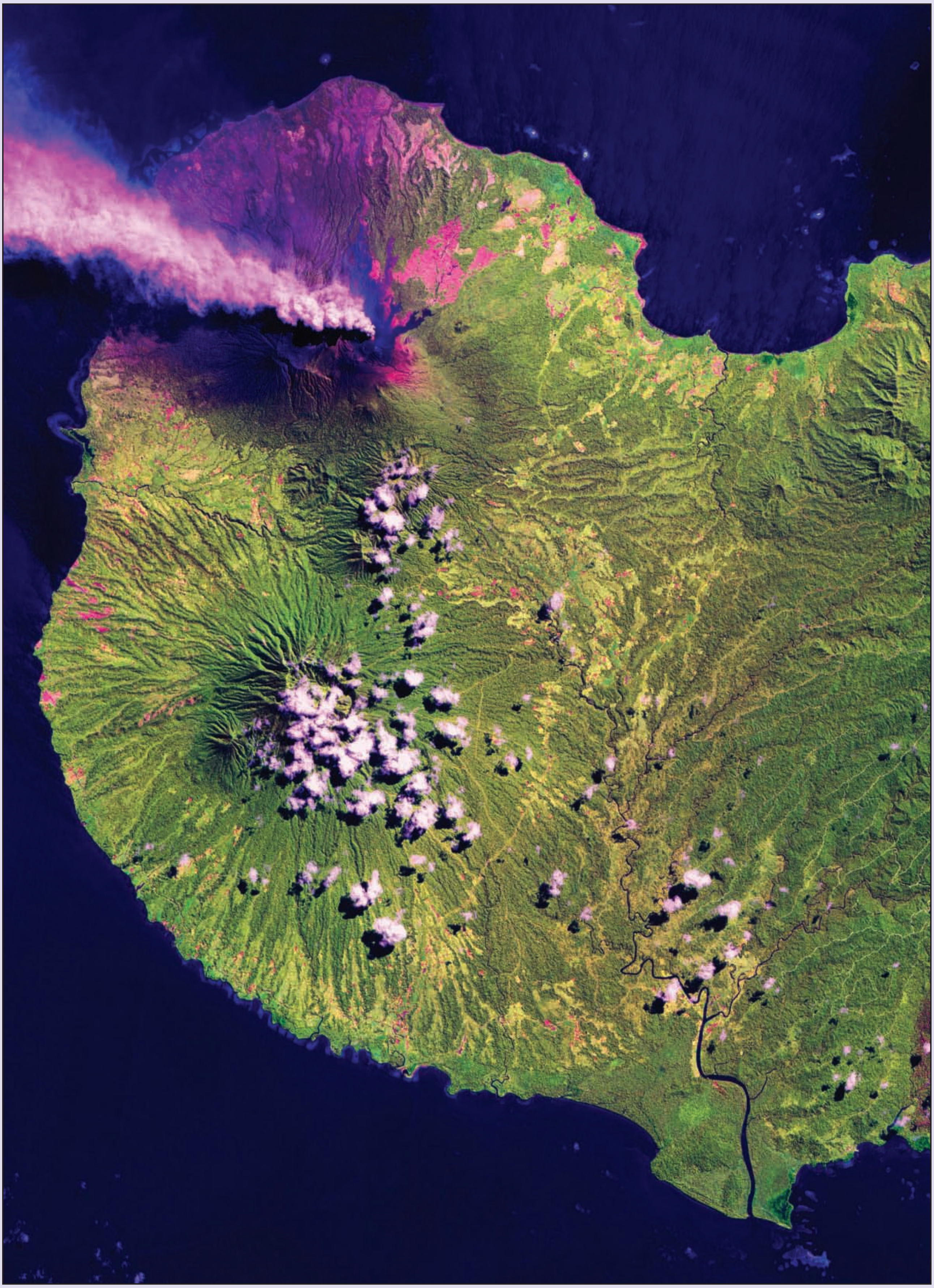
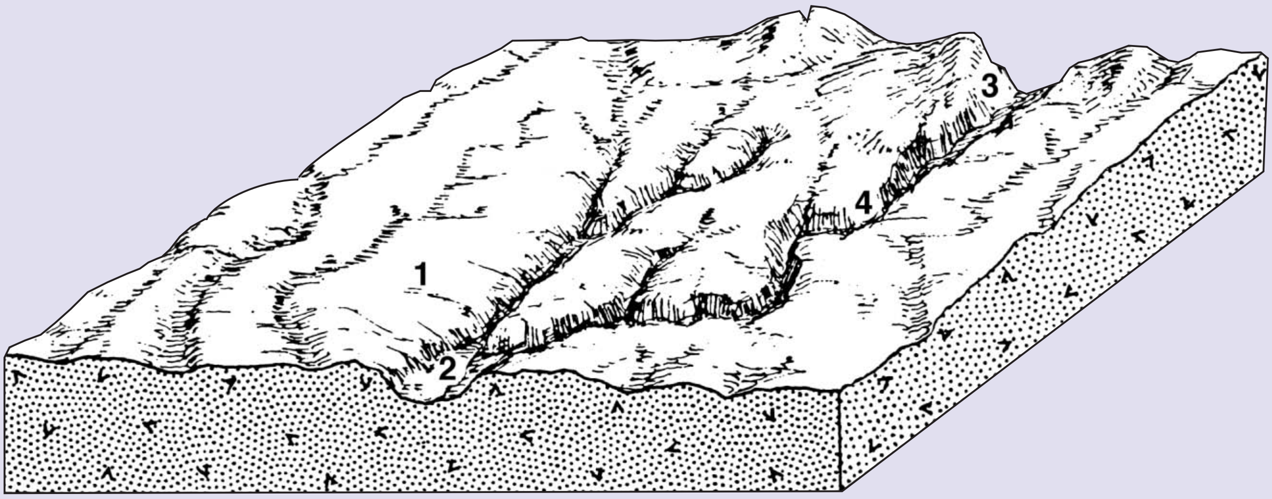


Figure 53: Mt Gulu, Cape Gloucester, West New Britain (SPOT4 image - June 2005). This volcano has been erupting for several years. Ash deposits are clearly visible. Logging operations are apparent in the centre and eastern portions of the image.

2.7.9.2 Volcanic fans and footslopes

32 **Little dissected volcanic footslopes and volcano-alluvial fans**. (Figure 54). A variety of undissected to little dissected landforms generally surrounding young or recently active volcanoes and including partly dissected extensive coalescing volcano-alluvial fans of slightly concave profile, formed of intercalated fluvial, laharic (mudflow) and nuee deposits in varying proportions with superficial air-borne ash. Fans are dissected by shallow frequently steep sided radiating valleys separated by either long low ridges with accordant crests or by undulation plains at lower altitudes and slopes (e.g. Bougainville Is., S.E Papua, and Southern Highlands Province). Gently undulating undissected to slightly dissected ash, alluvial, and mudflow plain surfaces with some poorly drained parts. The narrowly incised drainage pattern is widely spaced with larger rivers in incised steep sided valleys (e.g. in Enga and Western Highlands Provinces). Broad relict plains of sandy and gravely volcanic alluvium formed by coalescing volcano-alluvial fans and traversed by small terraced streams (e.g. Bougainville Is.).



1. Gently undulating coalescing volcano alluvial fans with some poorly drained parts and slopes less than 5º
2. Floodplain and terraces
3. Steep slopes of spurs and incised valleys
4. Very steep to precipitous slopes of incised valleys
5. Broad relict plain sloping up to 2º

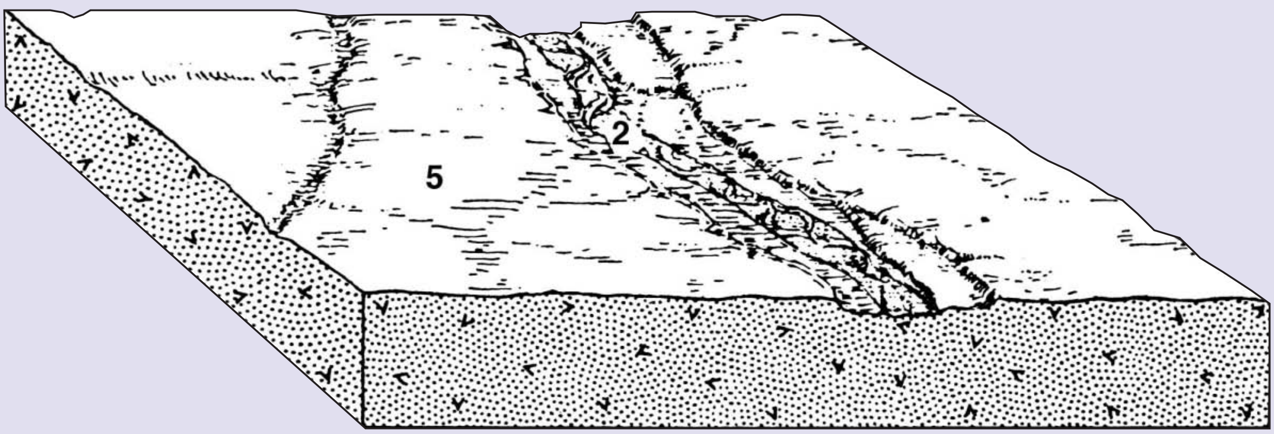
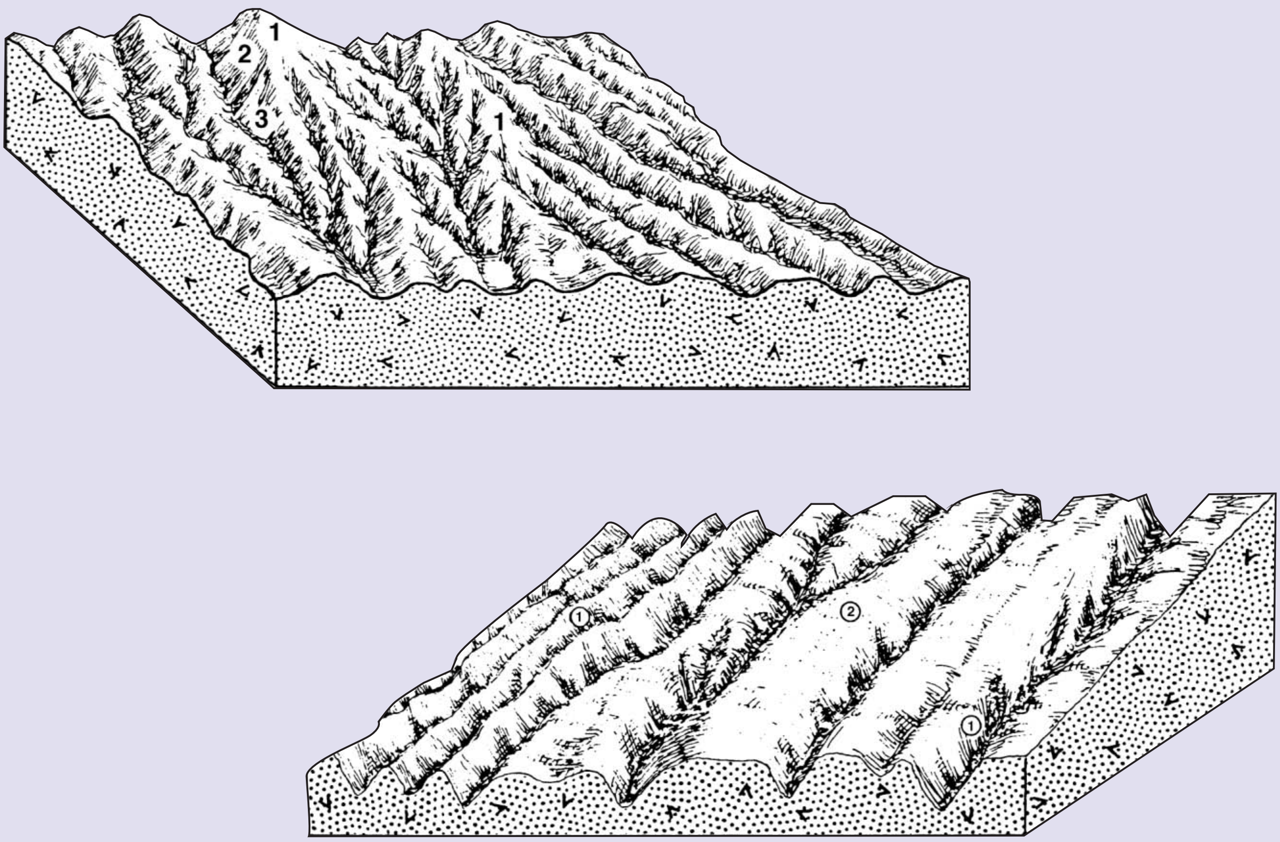


Figure 54: Volcano-alluvial fans and plains near Mendi consisting of gently undulating ash plains rising to dissected volcanic footslopes (background). The plains are both poorly and well to imperfectly drained. The better drained parts include some of the best land in the Highlands and are intensively used for gardening.

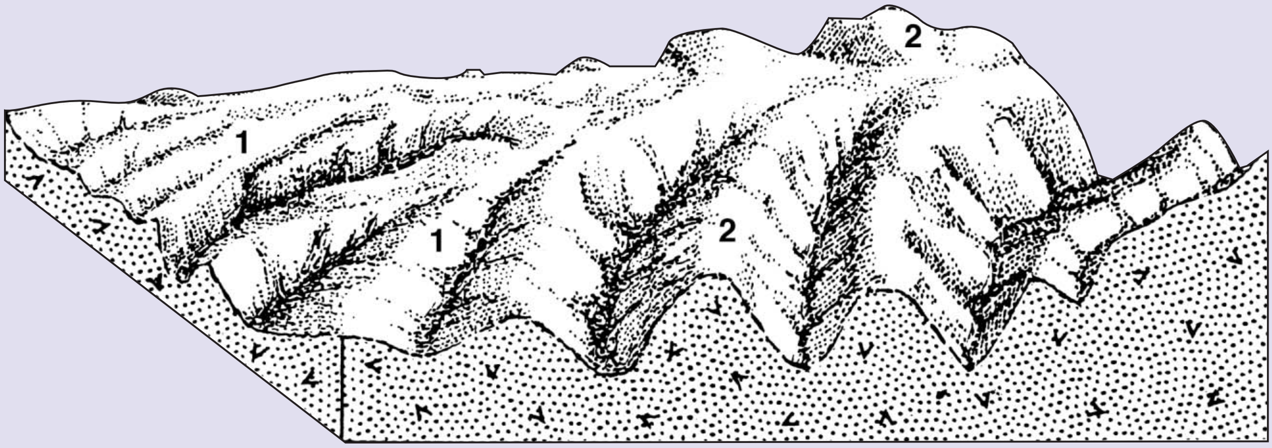
33 Dissected volcanic footslopes and volcano-alluvial fans (Figure 55). Dissected volcanic footslopes and former volcano-alluvial fans of slightly concave profile, formed of intercalated fluvial, laharic (mudflow), and nuee (avalanche) deposits with superficial ash. On the flanks of major volcanoes, they are dissected by numerous radiating streams to form a pattern of long, radiating or subparallel ridges and narrow, steep sided valleys.



1. Narrow ridge crests
2. Very steep hill slopes (30 to 50º)
3. Steep slopes of spurs and incised valleys
4. Broader undulating surfaces with slopes up to 20º

Figure 55: Extensive dissected gently sloping fans at the foot of the active volcano Mt Lamington (background) formed mainly of volcanic material transported down the mountain by lahars (mudflows) and glowing avalanches (flows of incandescent volcanic material carried by hot air and volcanic gases). This photograph taken in February 1951 shortly after Mt Lamington erupted clearly shows the effect of the eruption on the vegetation and the radial drainage pattern.

34 **Deeply dissected older volcanic footslopes and fans** (Figure 56). Broadly dissected lower flanks of deeply dissected older extinct volcanic centres consisting of long radial ridges with accordant crests separated by deep radial gorges. On the lower slopes valleys are U-shaped and separated by triangular shaped footslope remnants (planezes) and along the coast they frequently form drowned valleys or fjord-like inlets separated by narrow planezes.



1. Rolling surfaces and low rounded hill ridges with slopes up to 20º with U-shaped valleys
2. Steep sided (20 to 40º) rounded spurs and V-shaped valleys

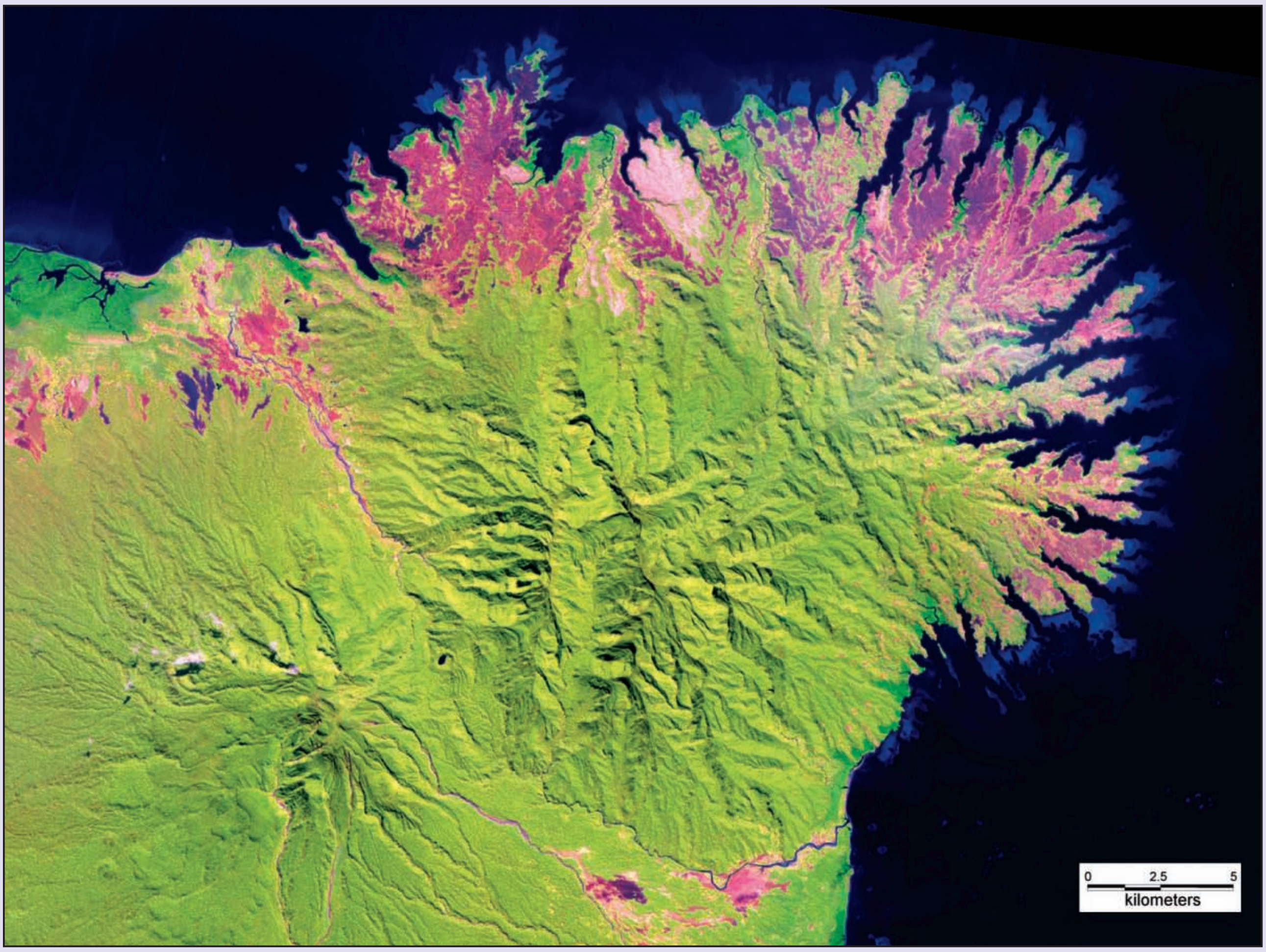
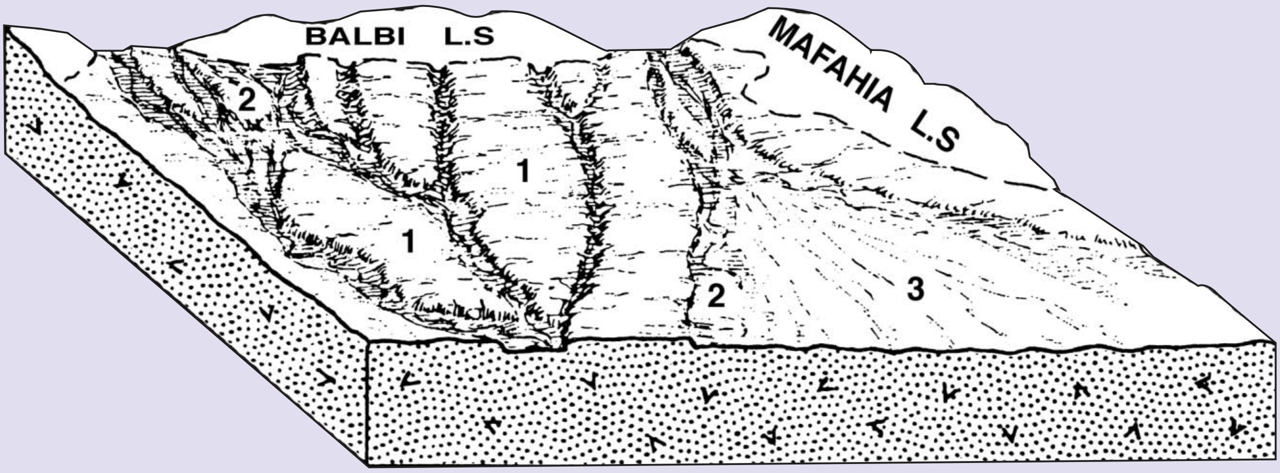
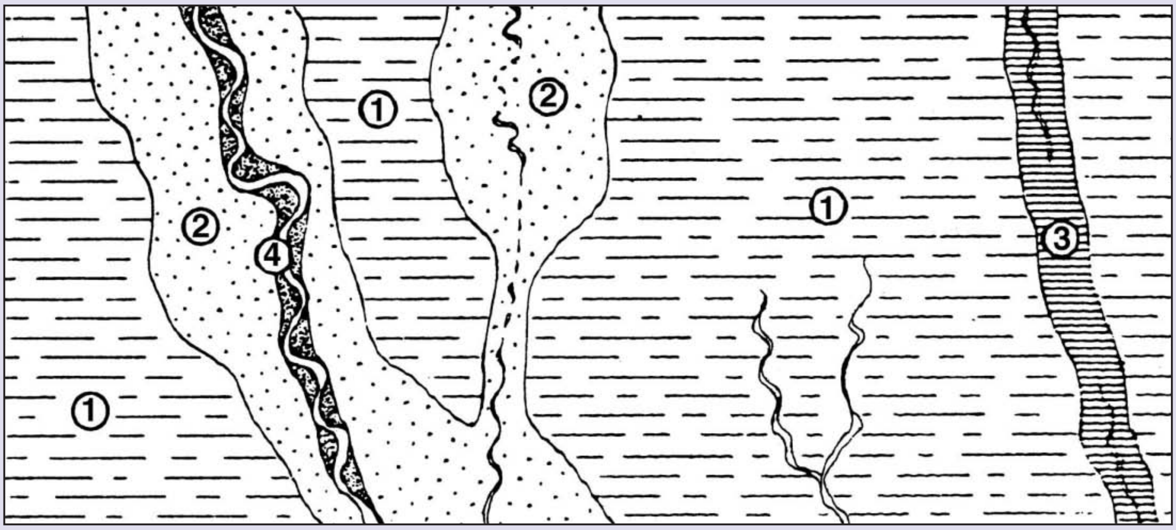


Figure 56: Cape Nelson with the deeply eroded extinct volcano, Mt Trafalgar. The original volcanic surface has been reduced by erosion to narrow ridge crests and only the crest accordance and radial drainage pattern indicate the former volcanic footslopes forming deeply dissected older volcanic footslopes forming deeply dissected planezes. The valleys are cut below present sea level and have subsequently been drowned producing a spectacular coast.

35 **Volcano-alluvial plains** (Figure 57, Figure 58). Actively forming very low angle volcanic plains which may take various forms:

- Coalescing volcano-alluvial and ash-covered plains with an associated unstable bar plain traversed by rapidly migrating braided streams.
- Stable alluvial plains formed of material derived largely from volcano-alluvial footslopes and fans deposited in fan fashion at the foot of volcanoes by rivers in flood. These plains have a very low gradient and are dissected by a few large rivers and many small radial streams.
- Fan-shaped, unstable volcanic outwash plains generally with a radial drainage pattern and subject to severe flooding. The main streams are braided, fast-flowing and well incised in the upper parts of the plain but in the lower parts are more meandering.





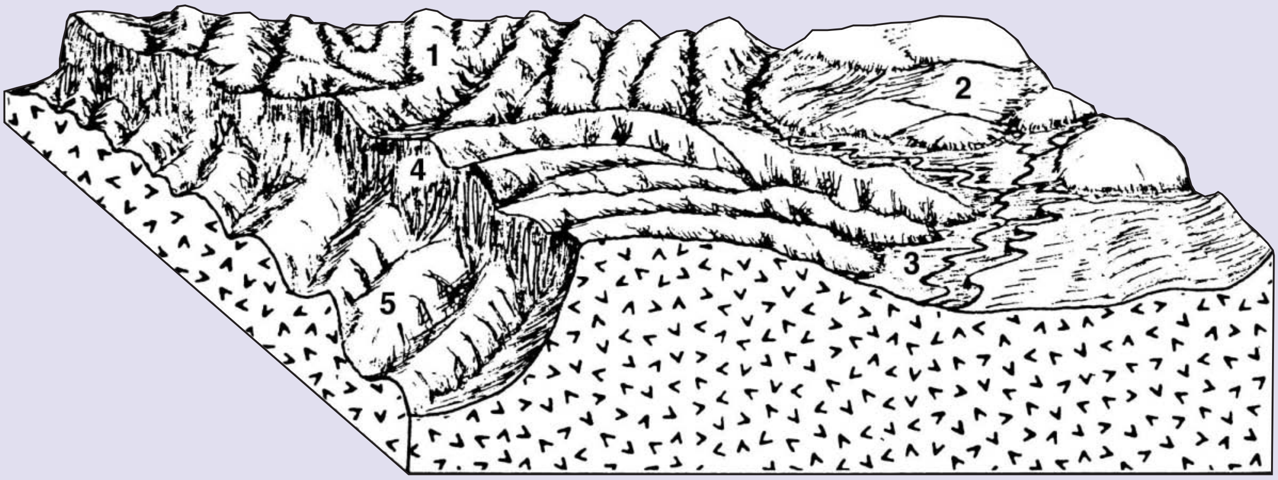
1. Stable volcano-alluvial plains
2. Bar plain with unstable braided stream channels
3. Fan shaped, unstable volcanic outwash plain
4. Floodplain and meandering channels

Figure 57: Active alluvial plain formed of material eroded from volcano-alluvial fans and traversed by the meandering channel of the Pirias River, Bougainville Island.

Figure 58: An unstable fan-shaped volcanic outwash (flood-out) plain traversed by the braided lower course of the Torokina River (Bougainville Island).

2.7.9.3 Volcanic plateaux

41 Dissected volcanic plateaux (Figure 59, Figure 60). Extensive elevated irregular surface of relatively low relief that is separated from the adjacent lowlands on one or more sides by escarpments. The summit area consists of closely spaced parallel or branching accordant low ridges formed on thick successions of gently dipping lava flows with some broadly undulating terrain in the lower parts of the plateau. The margins of the plateau are subject to severe erosion and consist of steep precipitous slopes forming scarps and knife-edged ridges.



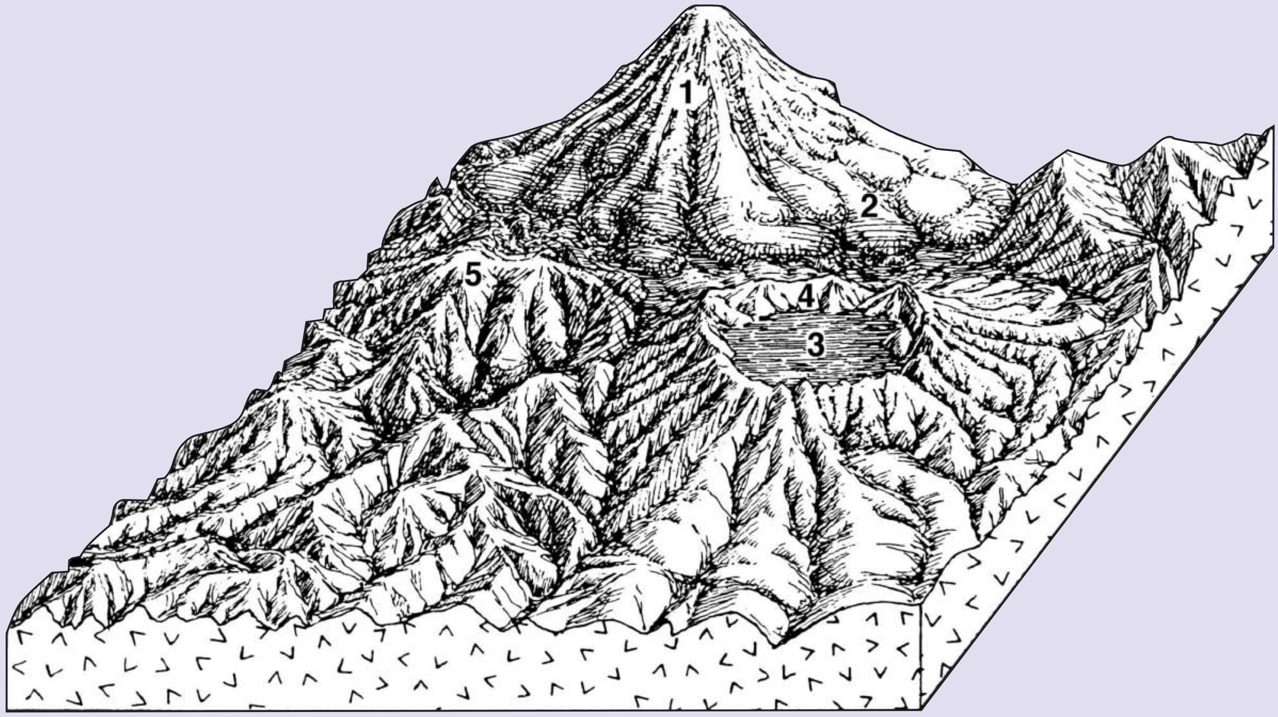
1. Closely spaced, parallel or branching ridges and spurs with short steep slopes
2. Broadly undulating very low hills with gentle slopes
3. Terraced floodplains of larger rivers
4. Precipitous escarpment with irregular steeped slopes and rock falls common
5. Parrallel massive ridges and spurs and prominent gullies with steep headslopes

Figure 59: Steep precipitous scarps up to 250m high bounding the Sogeri plateau north-east of Port Moresby (Central Province). The plateau is a broad synclinal structure that dips gently to the north-west and is formed on basalt and minor andesite agglomerate and tuff.

Figure 60: The deeply weathered volcanic rocks of the surface of the Sogeri plateau (Central Province) form closely spaced ridges and spurs with short steep slopes (background) with undulating terrain in the lower parts (foreground).

2.7.9.4 Mountains and hills

56 Volcanic cones and domes (Figure 61). Volcanic cones and domes encompass a wide variety of volcanic landforms which form high to very high mountains and include strato-volcanoes, lava shields, ash cones, scoria cones and caldera. The original surfaces of the volcanoes are preserved or at least partly preserved as flat but gently sloping interfluves with well developed radial drainage patterns. The great majority are strato-volcanoes or lava cones which are conical in shape, formed of lava flows and pyroclastics with ashflow and ashfall deposits, and typically with rugged summit areas including craters and parasitic cones, below which extensive debris slopes with occasional parasitic cones, form a concave outline to their transition to broad peripheral volcano-alluvial fans. Most of the younger volcanoes and all the more recently active ones are little dissected or only partly dissected and include Mt Bagana, Mt Ulawun, Manam Is., Mt Bosavi, Mt Lamington and Mt Victory. Lava shields, like Mt Giluwe, have broad convex profiles and are formed predominantly of highly fluid lava flows. Calderas, volcanic depressions several kilometres across and bounded by high precipitous walls, are common in parts of New Britain. The more strongly dissected cones and domes encompass some of the more ancient volcanoes including Mt Trafalgar and Hydrographers Range in Northern Province, Mt Schrader and Mt Andrew in West New Britain Province and the Emperor Range and other ranges of northern Bougainville Island. The original volcanic surfaces have been reduced by erosion to narrow ridge crests with occasional large steep sided amphitheatre-headed valleys. Only the crest accordance of the ridges and the radial drainage pattern indicate the former volcanic landform.



Basalt

1. Sinuous lava flows forming a craterless lava cone with steep to very steep slopes
2. Less steep concave debris slopes traversed by stream beds
3. Crater floor, sometimes forming a lake
4. Precipitous scarps forming margins of exploration craters, commonly with waterfalls
5. Steep sided knife-edged or very narrow ridges and erosional hill slopes

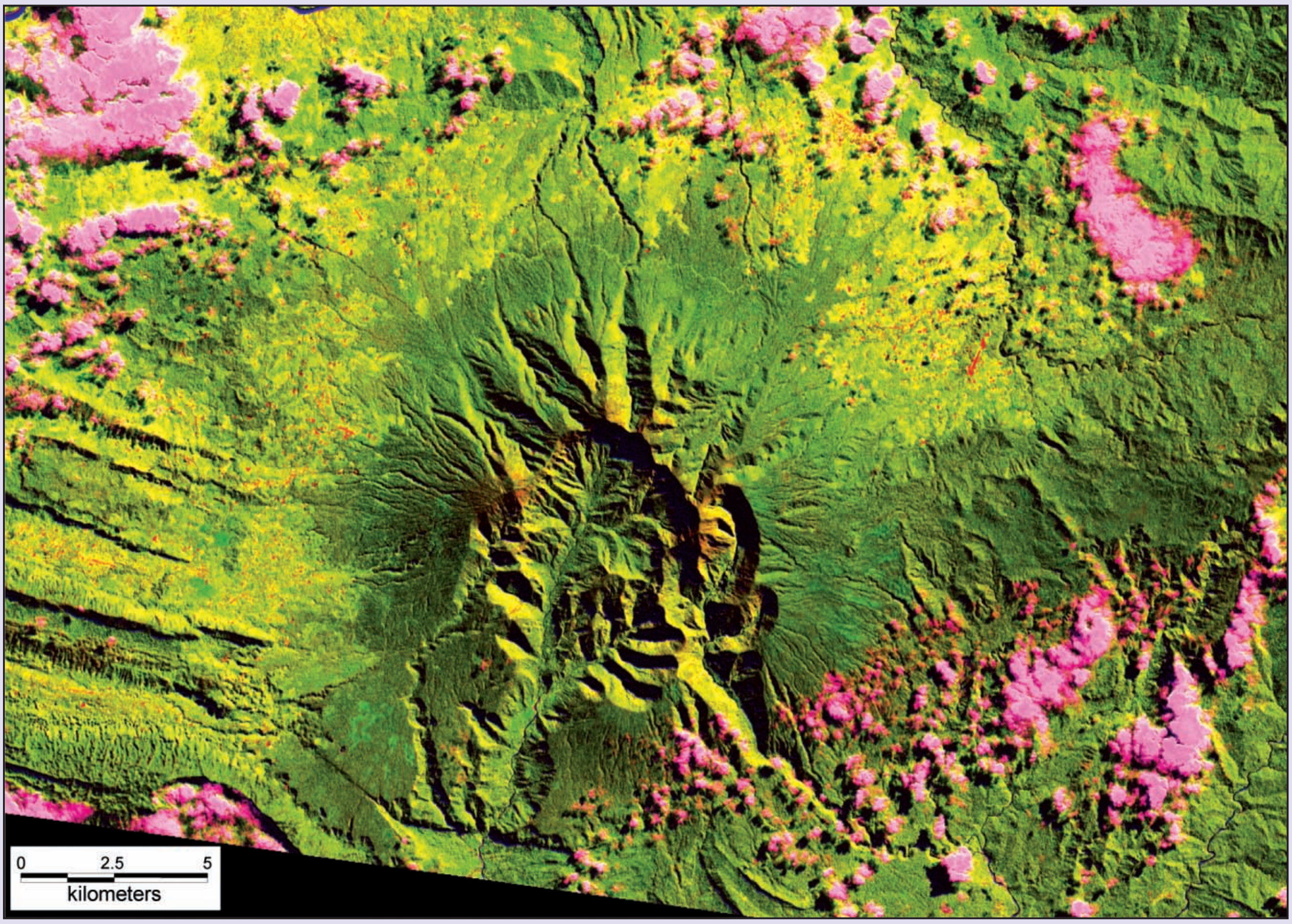


Figure 61: Satellite imagery of the volcano Mt Karimui and the rugged limestone ridges of the Masi syncline. Mt Karimui is an inactive strato-volcano with a huge crater, enlarged by erosion and breached to the south and surrounded by extensive little dissected volcano-alluvial footslopes. The syncline (west) consists of three limestone plates thrust upon one another and subsequent erosion has formed ridges where karst landforms have developed. Mt Karimui erupted during the Pleistocene and filled the sedimentary depressions between the ridges with ash flow.

2.7.10 Water bodies

60 **Lake** (Figure 62). Large permanent water-filled depression, formed either in the closed basin of a blocked valley, or in a karst area, or in the caldera of a volcano. Blocked valley lakes develop in smaller tributaries that have been blocked when relatively more rapid sedimentation along the main stream cuts off the tributaries that have been blocked when relatively more rapid sedimentation along the main stream cuts off the tributaries at their outlets forming a lake fed by commonly fresh water and usually associated with collapsed or partially or completely sealed dolines. Volcanic explosion crater lakes tend to be circular, closed, saline, and fed by runoff water from the crater slopes.

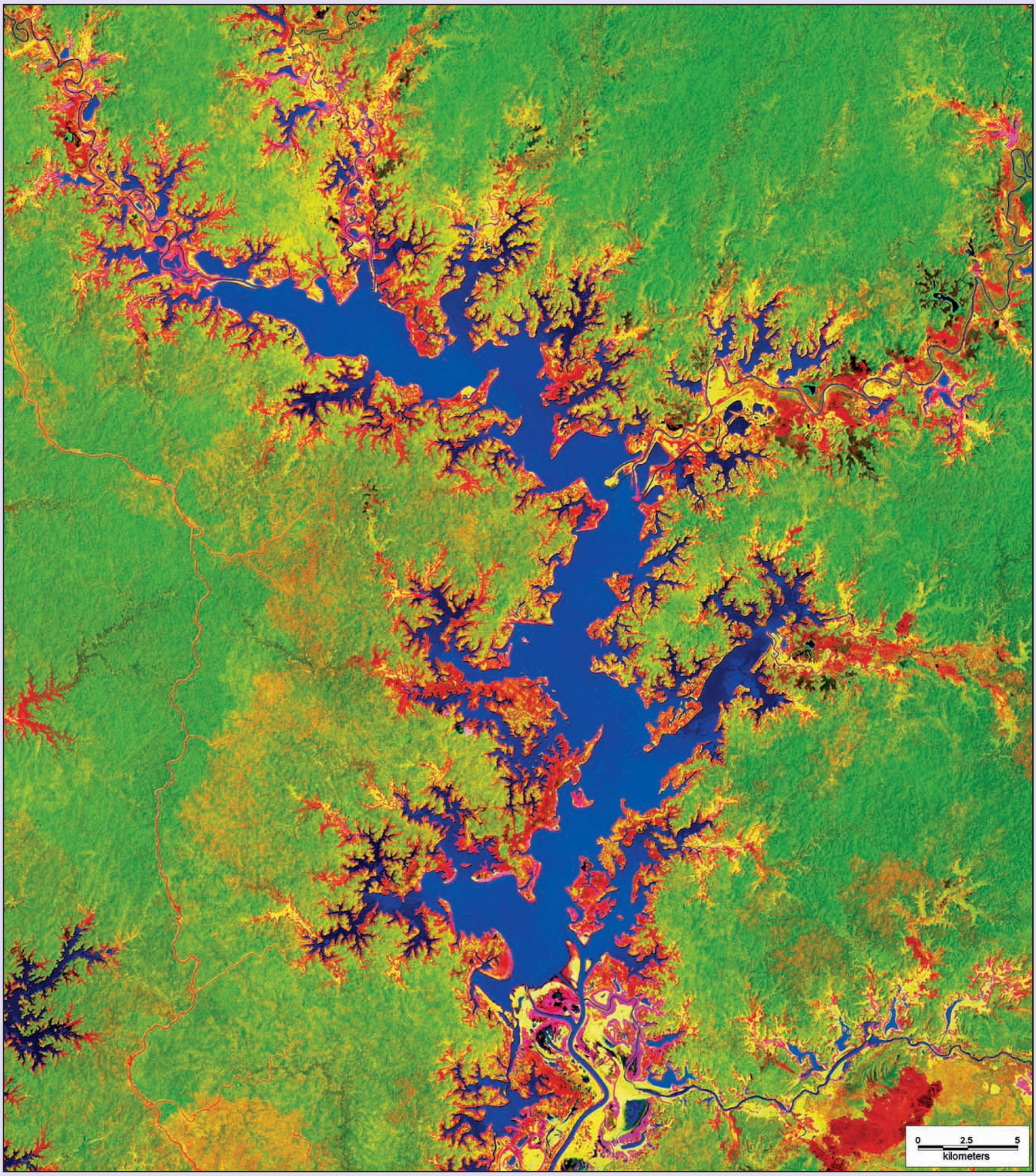


Figure 62: Lake Murray (Western Province), formed in the drowned valley of the Herbert River, mainly consists of open water. Swamp grass forming a dense matted cover finds a foothold in shallow water along the shores of the lake and around many islets in numerous embayments, and on submerged silt banks of streams flowing into the lake.

3 Climatic map layers

3.1 Introduction

There are five climatic attributes included in the upgraded PNGRIS. These attributes are; mean annual rainfall, rainfall seasonality, mean annual maximum temperature, mean annual minimum temperature and mean annual solar radiation.

3.1.1 Data sources

The source of the upgraded rainfall and temperature layers was the Worldclim climatic data system (Hijmans et al, 2005). Rainfall and temperature data were compiled using information recorded at weather stations from sites across PNG. These data were interpolated between weather stations using a DEM based on the SRTM data (discussed in section 2.2.2) aggregated to a 1km resolution. This process created gridded temperature and rainfall surfaces. The mean annual solar radiation layer was derived from a grid of solar radiation produced as part of the Biorap dataset (Nix et al, 2000). The radiation grid in BioRap was created using the Bioclim (Houlder et al, 2000) program which used a 1km DEM derived from the ANUDEM system as well weather station data from PNG, to interpolate annual mean radiation across the whole of PNG (Nix et al, 2000).

3.1.2 Limitations

All of the climate surfaces were created from 1km digital elevation models. For this reason local scale variation in climate was not captured. The estimates of rainfall, temperature and radiation are also derived from a limited number of weather stations across the country. For this reason, climatic measurements for places in PNG which are remote from a weather station may be less accurate than those estimates which are close to weather stations.

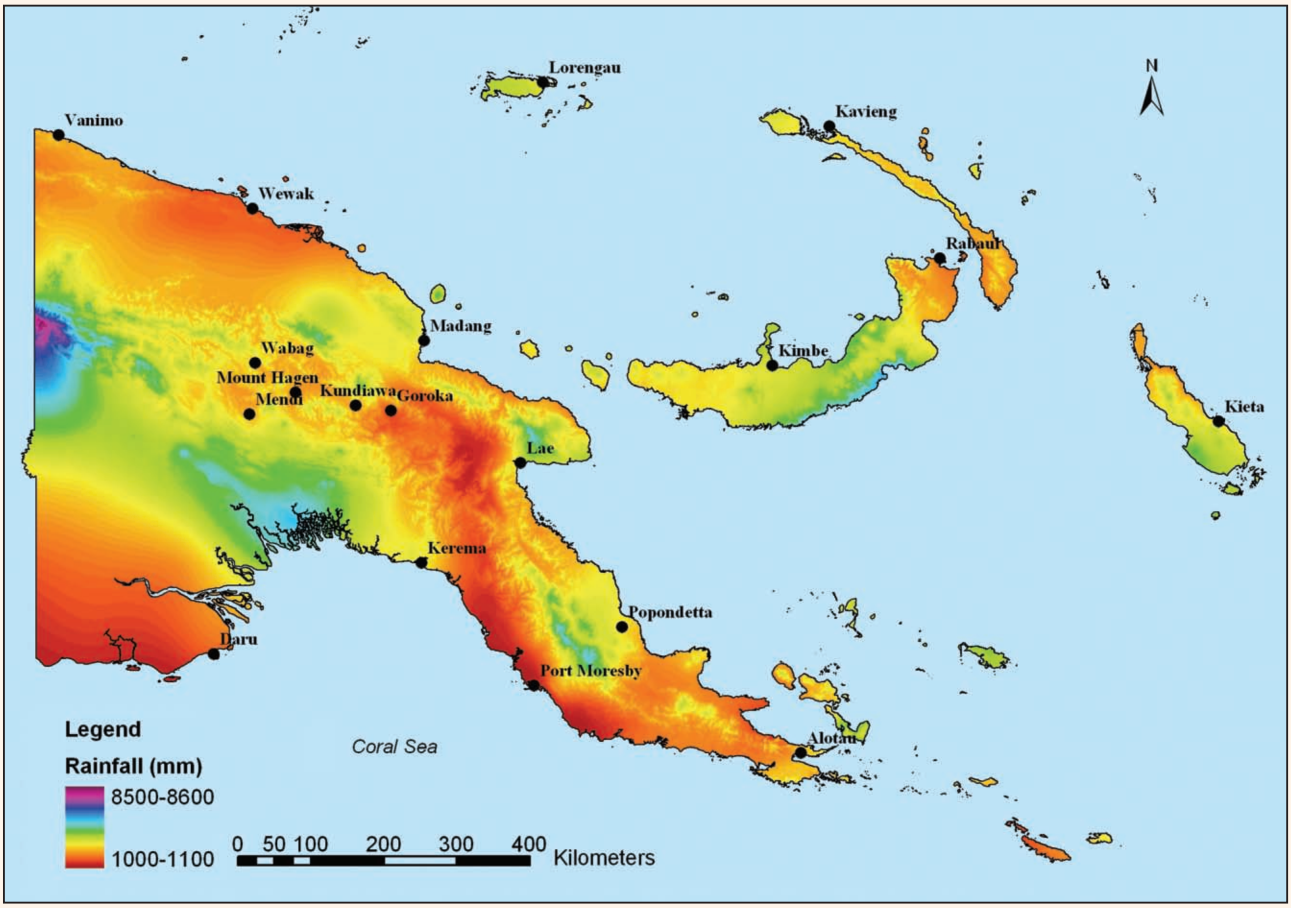
3.2 Mean annual rainfall

3.2.1 Classification

The upgraded PNGRIS mean annual rainfall layer is measured in millimetres of rainfall. Rainfall was divided into 100mm classes. There are a total of 76 classes in PNG. These classes are listed in Table 7. The rainfall map of PNG is shown in Figure 63.

Table 7: Mean annual rainfall classification used in the PNGRIS upgrade (the complete list of classes is shown in Appendix 2)

Code	Mean Annual Rainfall (mm)	Code	Mean Annual Rainfall (mm)
1	1000 – 1100	39	4800 – 4900
2	1100 – 1200	40	4900 – 5000
3	1200 – 1300	41	5000 – 5100
4	1300 – 1400	42	5100 – 5200
5	1400 – 1500	43	5200 – 5300
6	1500 – 1600	44	5300 – 5400
7	1600 – 1700	45	5400 – 5500
8	1700 – 1800	46	5500 – 5600
9	1800 – 1900	47	5600 – 5700
10	1900 – 2000	48	5700 – 5800
11	2000 – 2100	49	5800 – 5900
12	2100 – 2200	50	5900 – 6000
13	2200 – 2300	51	6000 – 6100
14	2300 – 2400	52	6100 – 6200
15	2400 – 2500	53	6200 – 6300
16	2500 – 2600	54	6300 – 6400
17	2600 – 2700	55	6400 – 6500
18	2700 – 2800	56	6500 – 6600
19	2800 – 2900	57	6600 – 6700
20	2900 – 3000	58	6700 – 6800
21	3000 – 3100	59	6800 – 6900
22	3100 – 3200	60	6900 – 7000
23	3200 – 3300	61	7000 – 7100
24	3300 – 3400	62	7100 – 7200
25	3400 – 3500	63	7200 – 7300
26	3500 – 3600	64	7300 – 7400
27	3600 – 3700	65	7400 – 7500
28	3700 – 3800	66	7500 – 7600
29	3800 – 3900	67	7600 – 7700
30	3900 – 4000	68	7700 – 7800
31	4000 – 4100	69	7800 – 7900
32	4100 – 4200	70	7900 – 8000
33	4200 – 4300	71	8000 – 8100
34	4300 – 4400	72	8100 – 8200
35	4400 – 4500	73	8200 – 8300
36	4500 – 4600	74	8300 – 8400
37	4600 – 4700	75	8400 – 8500
38	4700 – 4800	76	8500 – 8600



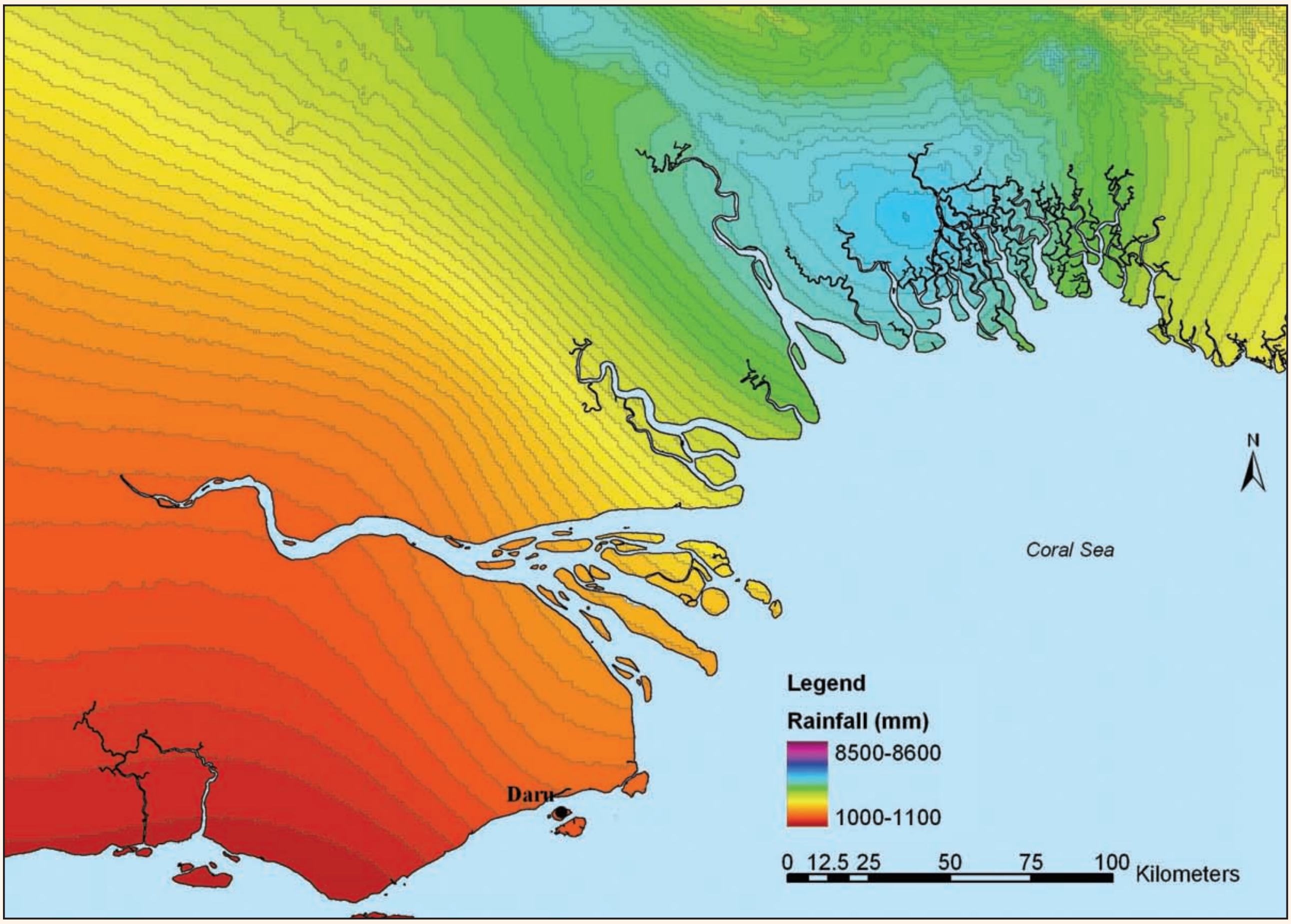


Figure 63: Mean annual rainfall. The upper map shows the rainfall layer containing 100mm rainfall classes for the whole of PNG. The lower map shows a close-up view in Western and Gulf Provinces.

3.2.2 Data sources

The source of the mean annual rainfall map layer was the Worldclim climatic data system (Hijmans et al, 2005).

3.2.3 Method

Data from each of the monthly rainfall surfaces were combined using the ESRI Arcinfo GIS to produce one mean annual rainfall grid. This grid was then reclassified in Arcinfo into 100mm classes and then converted to a vector layer. The rainfall map was then fitted to the PNG coastline and translated into MapInfo vector format.

3.3 Rainfall seasonality

3.3.1 Classification

The classification used to describe rainfall seasonality is identical to that used in the previous version of PNGRIS. The seasonal variability of mean monthly rainfall is classified according to ‘estimated amounts, range and dominant levels of monthly rainfall throughout the year’ (Bellamy & McAlpine, 1995, p87) which is based on the work of Fitzpatrick et al. (1966). Rainfall seasonality classes used in the PNGRIS upgrade are outlined in Table 8. The rainfall seasonality map layer for PNG is shown in Figure 64.

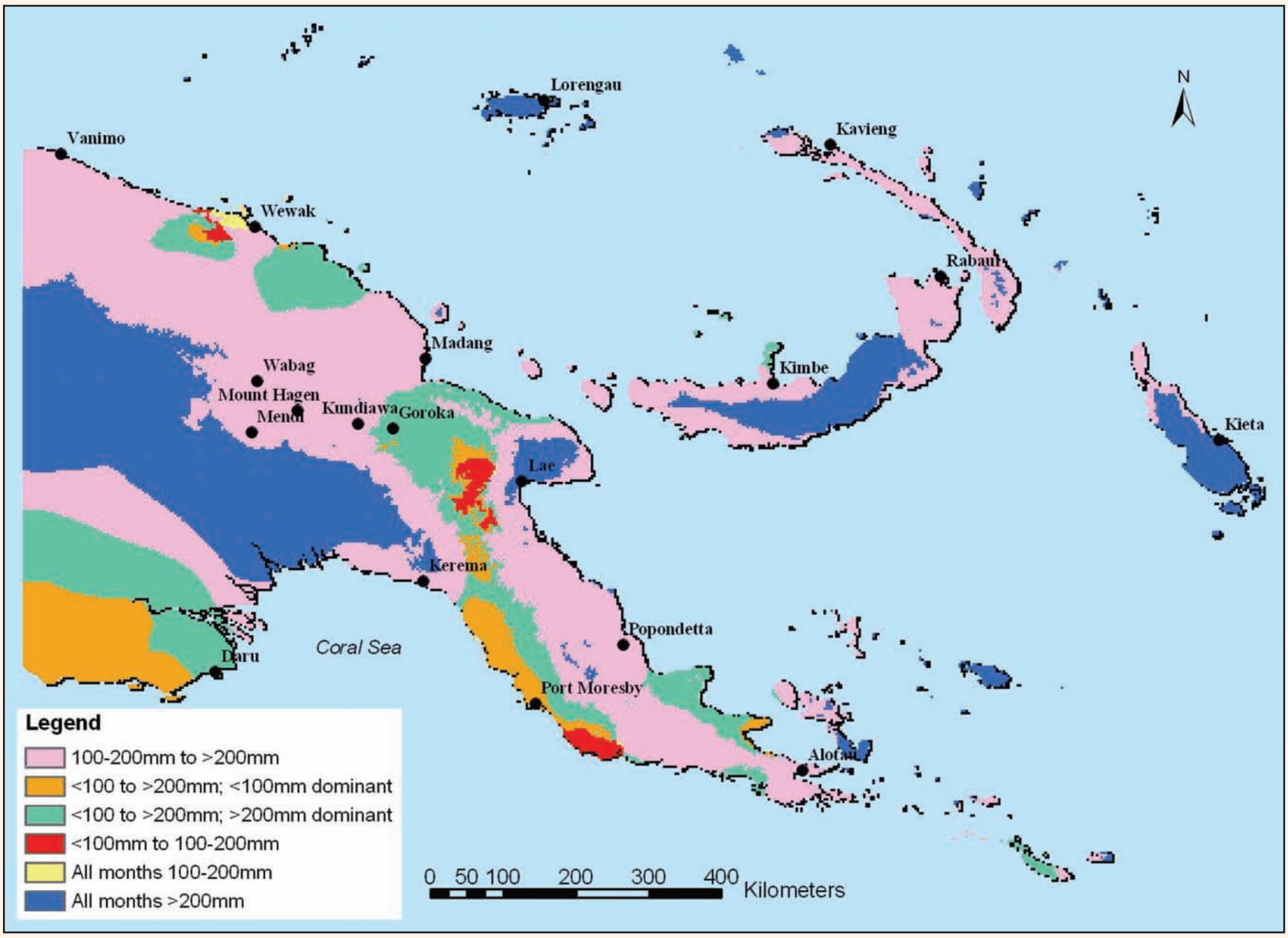


Figure 64: Rainfall seasonality map for PNG. Rainfall seasonality is based on levels of monthly rainfall.

Table 8: Classification system used to describe rainfall seasonality

Code	Rainfall per month	Description
1	<100mm to >200mm; >200mm dominant	Large rainfall range, heavy to light monthly rainfall, heavy dominant
2	<100mm to >200mm; <100mm dominant	Large rainfall range, heavy to light monthly rainfall, Light dominant
3	100 – 200mm to >200mm	Moderate rainfall range, heavy to intermediate monthly rainfall
4	<100mm to 100 – 200mm	Moderate rainfall range, intermediate to light monthly rainfall
5	All months >200mm	Continuously heavy monthly rainfall
6	All months 100 – 200mm	Continuously intermediate monthly rainfall

3.3.2 Data sources

Rainfall seasonality was created from the Worldclim global monthly rainfall grids (Hijmans et al, 2005).

3.3.3 Method

A rainfall seasonality grid was produced in Arcinfo using each of the 12 monthly rainfall grids according to the system outlined in Table 8. The classified rainfall seasonality grid was then converted to a vector layer and fitted to the PNG coastline. The rainfall seasonality layer was then translated into MapInfo vector format.

The process of producing a rainfall seasonality map involved creating a minimum and a maximum monthly rainfall grid. A minimum monthly rainfall grid showing the lowest monthly rainfall achieved during the year was calculated from each of the 12 monthly rainfall grids using Arcinfo. A maximum monthly rainfall grid showing the highest monthly rainfall achieved through the year was also created. The minimum and maximum monthly rainfall grids were sufficient to produce a seasonality map showing classes 3, 4, 5, and 6 described in Table 15, however class 1 and 2 were combined into one class. In order to separate classes 1 and 2, two more grids were required, one showing the number of months where rainfall was greater than 200mm and one showing the number of months where rainfall was less than 100mm. These two grids were calculated in Arcinfo using the 12 monthly rainfall grids. If more months received rainfall greater than 200mm compared to the number of months receiving rainfall less than 100mm, then rainfall seasonality class 1 was assigned to that location. Similarly, if more months received less than 100mm compared to the number of months where more than 200mm fell, then that location was assigned to rainfall seasonality class 2.

3.4 Temperature

The upgraded PNGRIS temperature layers are measured in degrees celsius. In Papua New Guinea there is a strong relationship between temperature and elevation at altitudes greater than 500m. Annual maximum temperature decreases at a rate of 0.535^{o}C per 100m increase in altitude, and annual minimum temperature decreases at a rate of 0.672^{o}C per 100m increase in altitude (McAlpine et al, 1983). The digital elevation model (DEM) described in section 2.2 was created from a 90m resolution grid and therefore shows considerably more detail than the temperature grids contained in the Worldclim climatic dataset, which have a resolution of 1km. For this reason, users exclusively working at elevations greater than 500m may wish to use the elevation map described in section 2.2 as a surrogate for temperature. For areas above 500m altitude, the elevation layer can be converted to an annual maximum temperature layer and an annual minimum temperature layer by joining the remap tables shown in Table 9 and Table 10 to the elevation layer in MapInfo. Mean annual maximum temperature, and mean annual minimum temperature were created from the elevation layer using the formulas:

- Max.Temp = -0.00672 x elevation(m) + 35.0 (McAlpine et al, 1983 p95)
- Min.Temp = -0.00535 x elevation(m) + 22.0 (McAlpine et al, 1983 p95)

However for the lowlands and coastal areas in PNG below 500m elevation, temperature cannot be inferred directly from altitude, and the map of temperature derived from the Worldclim gridded climate surfaces described below should be used.

The mean annual minimum temperature map layer for PNG is shown in Figure 65. The mean annual maximum temperature map layer is shown in Figure 66.

Table 9: Remap table for converting the upgraded PNGRIS elevation layer to an annual maximum temperature layer for areas above 500m only

Code	Elevation/Altitude class (m)			Mean Annual Maximum Temperature (^oC)		
6	500	–	600	31.6	–	31.0
7	600	–	700	31.0	–	30.3
8	700	–	800	30.3	–	29.6
9	800	–	900	29.6	–	29.0
10	900	–	1000	29.0	–	28.3
11	1000	–	1100	28.3	–	27.6
12	1100	–	1200	27.6	–	26.9
13	1200	–	1300	26.9	–	26.3
14	1300	–	1400	26.3	–	25.6
15	1400	–	1500	25.6	–	24.9
16	1500	–	1600	24.9	–	24.2
17	1600	–	1700	24.2	–	23.6
18	1700	–	1800	23.6	–	22.9
19	1800	–	1900	22.9	–	22.2
20	1900	–	2000	22.2	–	21.6
21	2000	–	2100	21.6	–	20.9
22	2100	–	2200	20.9	–	20.2
23	2200	–	2300	20.2	–	19.5
24	2300	–	2400	19.5	–	18.9
25	2400	–	2500	18.9	–	18.2
26	2500	–	2600	18.2	–	17.5
27	2600	–	2700	17.5	–	16.9
28	2700	–	2800	16.9	–	16.2
29	2800	–	2900	16.2	–	15.5
30	2900	–	3000	15.5	–	14.8
31	3000	–	3100	14.8	–	14.2
32	3100	–	3200	14.2	–	13.5
33	3200	–	3300	13.5	–	12.8
34	3300	–	3400	12.8	–	12.2
35	3400	–	3500	12.2	–	11.5
36	3500	–	3600	11.5	–	10.8
37	3600	–	3700	10.8	–	10.1
38	3700	–	3800	10.1	–	9.5
39	3800	–	3900	9.5	–	8.8
40	3900	–	4000	8.8	–	8.1
41	4000	–	4100	8.1	–	7.4
42	4100	–	4200	7.4	–	6.8
43	4200	–	4300	6.8	–	6.1
44	4300	–	4400	6.1	–	5.4

Table 10: Remap table for converting the upgraded PNGRIS elevation layer to an Annual Minimum Temperature layer for areas above 500m only

Code	Elevation/Altitude class (m)			Mean Annual Minimum Temperature (^{o}C)		
6	500	–	600	19.3	–	18.8
7	600	–	700	8.8	–	18.3
8	700	–	800	18.3	–	17.7
9	800	–	900	17.7	–	17.2
10	900	–	1000	17.2	–	16.7
11	1000	–	1100	16.7	–	16.1
12	1100	–	1200	16.1	–	15.6
13	1200	–	1300	15.6	–	15.0
14	1300	–	1400	15.0	–	14.5
15	1400	–	1500	14.5	–	14.0
16	1500	–	1600	14.0	–	13.4
17	1600	–	1700	13.4	–	12.9
18	1700	–	1800	12.9	–	12.4
19	1800	–	1900	12.4	–	11.8
20	1900	–	2000	11.8	–	11.3
21	2000	–	2100	11.3	–	10.8
22	2100	–	2200	10.8	–	10.2
23	2200	–	2300	10.2	–	9.7
24	2300	–	2400	9.7	–	9.2
25	2400	–	2500	9.2	–	8.6
26	2500	–	2600	8.6	–	8.1
27	2600	–	2700	8.1	–	7.6
28	2700	–	2800	7.6	–	7.0
29	2800	–	2900	7.0	–	6.5
30	2900	–	3000	6.5	–	6.0
31	3000	–	3100	6.0	–	5.4
32	3100	–	3200	5.4	–	4.9
33	3200	–	3300	4.9	–	4.3
34	3300	–	3400	4.3	–	3.8
35	3400	–	3500	3.8	–	3.3
36	3500	–	3600	3.3	–	2.7
37	3600	–	3700	2.7	–	2.2
38	3700	–	3800	2.2	–	1.7
39	3800	–	3900	1.7	–	1.1
40	3900	–	4000	1.1	–	0.6
41	4000	–	4100	0.6	–	0.1
42	4100	–	4200	0.1	–	-0.5
43	4200	–	4300	-0.5	–	-0.1
44	4300	–	4400	-0.1	–	-1.5

3.4.1 Classification

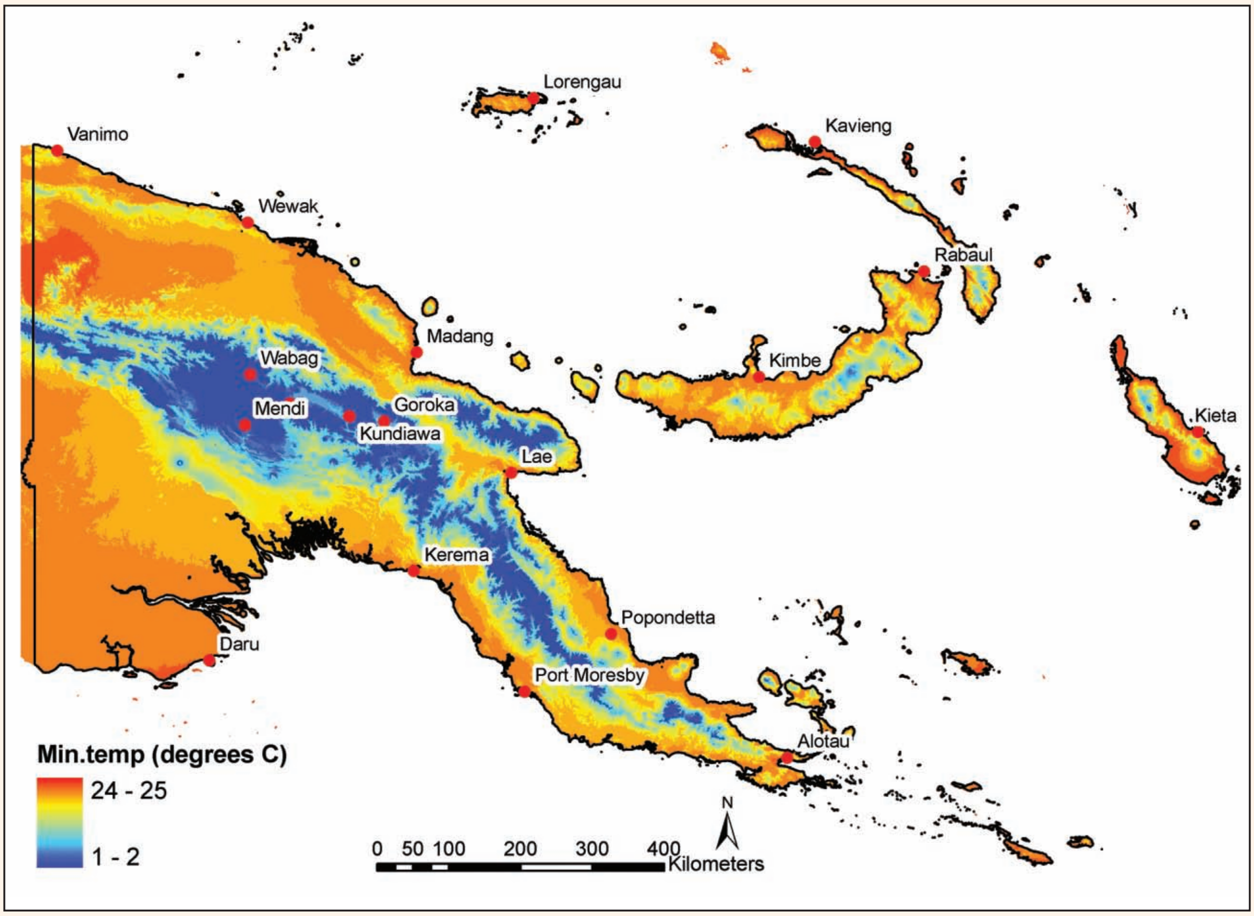
The upgraded PNGRIS temperature layers contain one class per one degree Celsius change in temperature. The classification schemes used in the PNGRIS upgrade to describe mean annual minimum and mean annual maximum temperature are presented in Table 11 and Table 12 respectively.

Table 11: Classification scheme used to describe mean annual minimum temperature

Code	Mean Annual Minimum Temperature (ºC)		
1	0.5	–	1.0
2	1.0	–	2.0
3	2.0	–	3.0
4	3.0	–	4.0
5	4.0	–	5.0
6	5.0	–	6.0
7	6.0	–	7.0
8	7.0	–	8.0
9	8.0	–	9.0
10	9.0	–	10.0
11	10.0	–	11.0
12	11.0	–	12.0
13	12.0	–	13.0
14	13.0	–	14.0
15	14.0	–	15.0
16	15.0	–	16.0
17	16.0	–	17.0
18	17.0	–	18.0
19	18.0	–	19.0
20	19.0	–	20.0
21	20.0	–	21.0
22	21.0	–	22.0
23	22.0	–	23.0
24	23.0	–	24.0
25	24.0	–	25.0

Table 12: Classification scheme used to describe mean annual maximum temperature

Code	Mean Annual Minimum Temperature (ºC)		
1	3.5	–	4.0
2	4.0	–	5.0
3	5.0	–	6.0
4	6.0	–	7.0
5	7.0	–	8.0
6	8.0	–	9.0
7	9.0	–	10.0
8	10.0	–	11.0
9	11.0	–	12.0
10	12.0	–	13.0
11	13.0	–	14.0
12	14.0	–	15.0
13	15.0	–	16.0
14	16.0	–	17.0
15	17.0	–	18.0
16	18.0	–	19.0
17	19.0	–	20.0
18	20.0	–	21.0
19	21.0	–	22.0
20	22.0	–	23.0
21	23.0	–	24.0
22	24.0	–	25.0
23	25.0	–	26.0
24	26.0	–	27.0
25	27.0	–	28.0
26	28.0	–	29.0
27	29.0	–	30.0
28	30.0	–	31.0
29	31.0	–	32.0
30	32.0	–	33.0
31	33.0	–	34.0



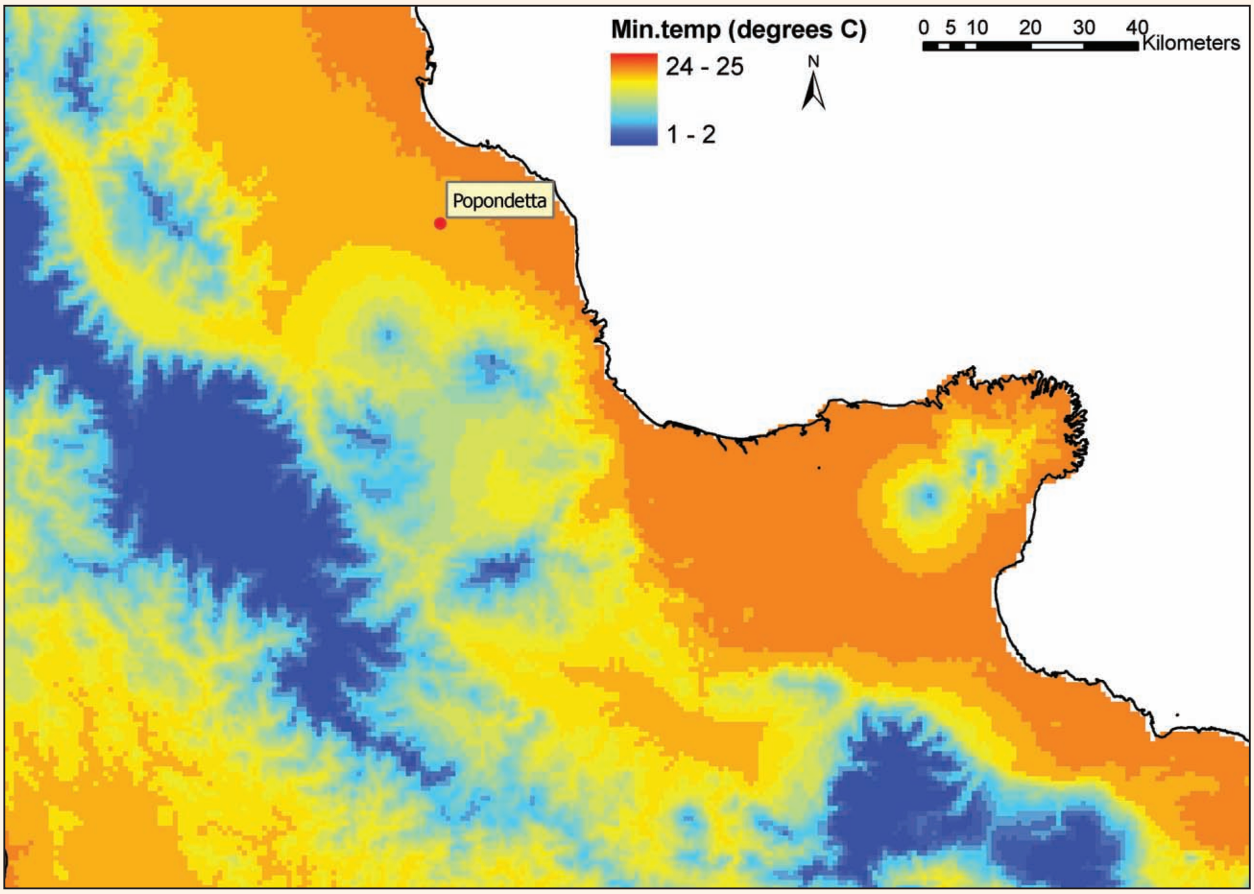
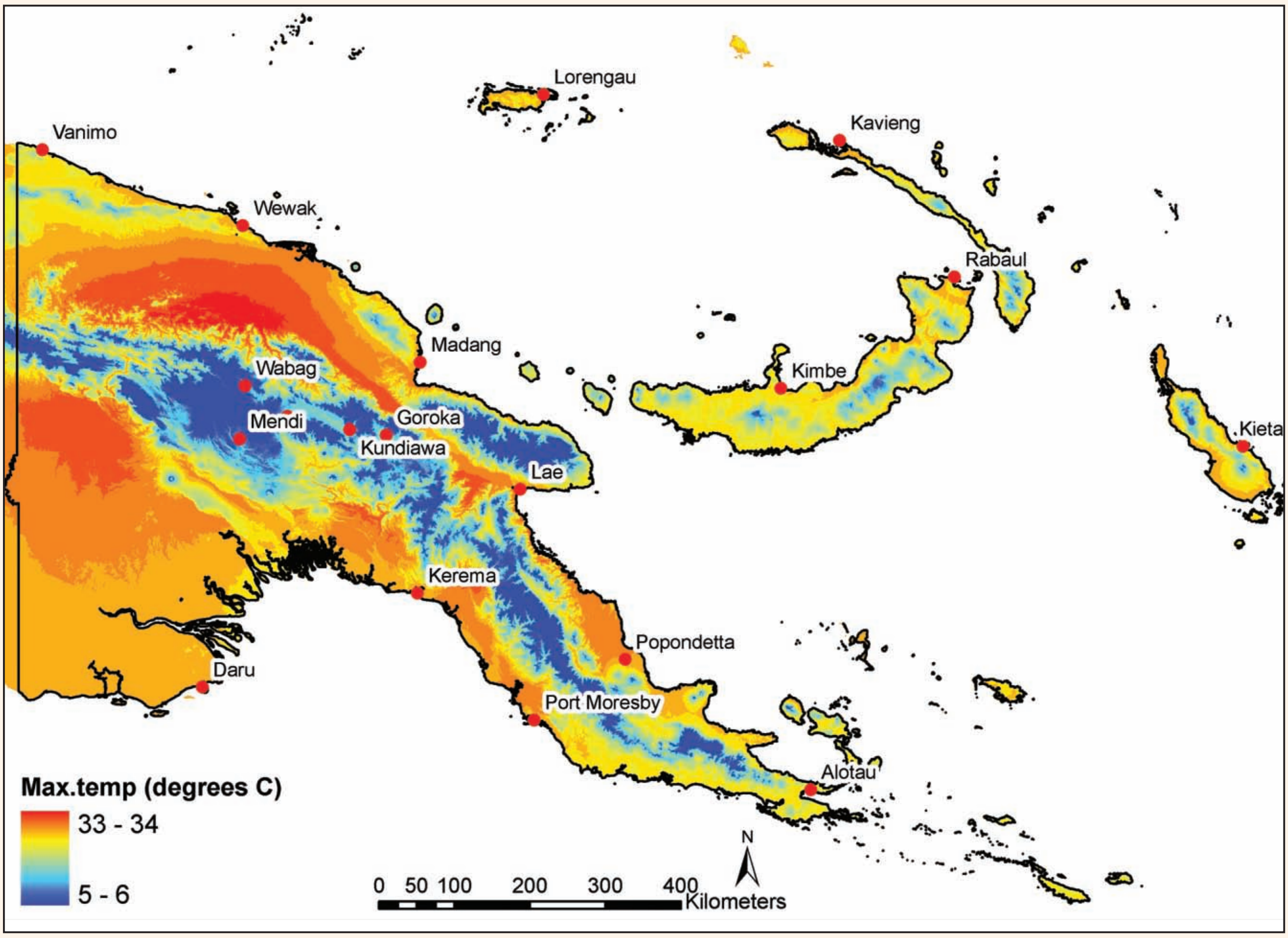


Figure 65: Mean annual minimum temperature. The upper image shows mean annual minimum temperature for the whole of PNG. The lower image shows a close-up view of mean annual minimum temperature around Popondetta, Oro Province.



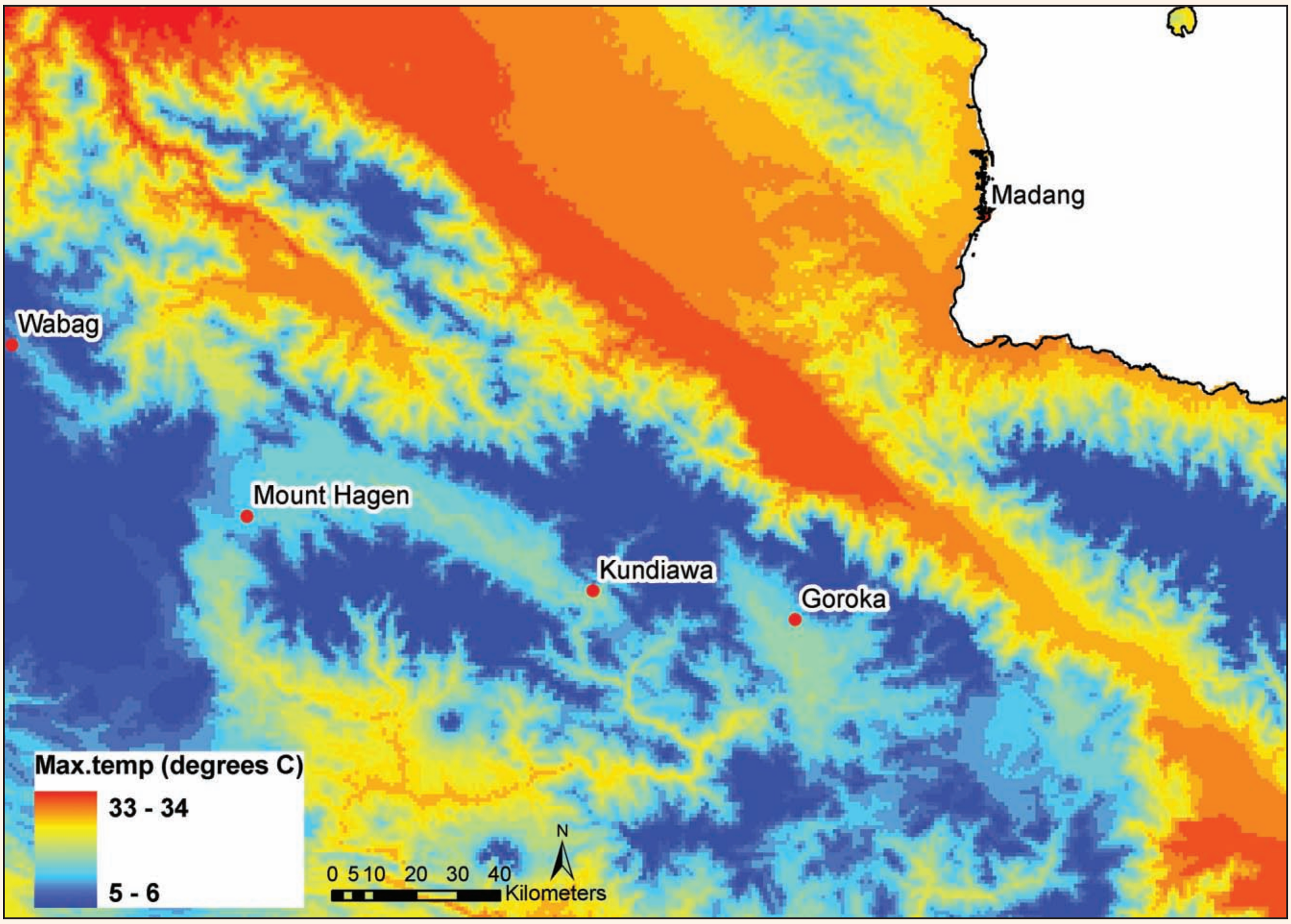


Figure 66: Mean annual maximum temperature. The upper image shows mean annual maximum temperature for the whole of PNG. The lower image shows mean annual maximum temperature in the Highlands.

3.4.2 Data sources

The source of the minimum and maximum temperature layers was the Worldclim monthly temperature grids (Hijmans et al, 2005).

3.4.3 Method

The mean annual maximum temperature layer was created by averaging each of the Worldclim monthly maximum temperature grids. The resultant maximum temperature grids were classified using Arcinfo into the classes shown in Table 11, and converted to MapInfo vector format. The same procedure was used to produce the mean annual minimum temperature layer, using the Worldclim minimum temperature grids. The resultant minumum temperature grids were classified using Arcinfo into the classes shown in Table 12, and converted to MapInfo vector format.

3.5 Mean annual solar radiation

3.5.1 Classification

The upgraded PNGRIS mean annual radiation layer is shown in Figure 67.

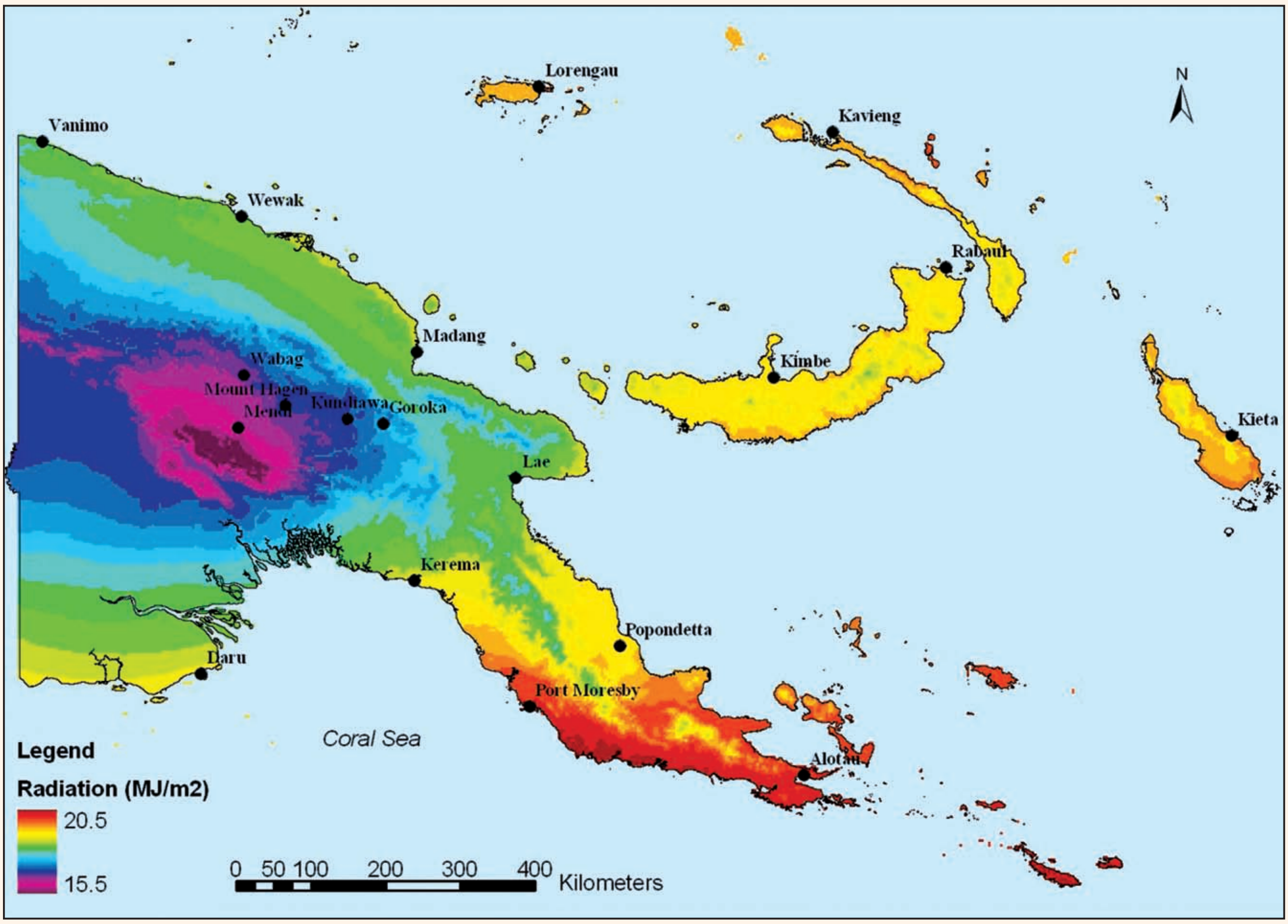


Figure 67: Mean annual radiation for PNG.

The PNGRIS mean annual solar radiation layer is measured in mega joules per square metre (MJ/m²). The classification scheme used to describe mean annual radiation is shown in Table 13.

Table 13. Classification describing mean annual solar radiation

Code	Mean Annual Radiation (MJ/m²)		
1	15.50	–	15.75
2	15.75	–	16.00
3	16.00	–	16.25
4	16.25	–	16.50
5	16.50	–	16.75
6	16.75	–	17.00
7	17.00	–	17.25
8	17.25	–	17.50
9	17.50	–	17.75
10	17.75	–	18.00
11	18.00	–	18.25
12	18.25	–	18.50
13	18.50	–	18.75
14	18.75	–	19.00
15	19.00	–	19.25
16	19.25	–	19.50
17	19.50	–	19.75
18	19.75	–	20.00
19	20.00	–	20.25
20	20.25	–	20.50

3.5.2 Data sources

The mean annual radiation layer was reclassified from the mean annual radiation grid contained in the BioRap dataset (Nix et al., 2000). The original unclassified mean annual radiation grid was generated by CRES for the BioRap project using a 1km resolution DEM and the BIOCLIM program (Houlder et al, 2000).

3.5.3 Method

The original mean annual rainfall grid was supplied in Idrisi format. This grid was imported into ArcInfo, reprojected to Geographic (AGD84) projection and reclassified according to the system outlined in Table 13. The classified grid was then converted to MapInfo vector format.

4 Geology map layer

4.1 Introduction

A geology layer is useful for agricultural planning because rock type is the parent material which contributes to soil formation. In regions that have not been surveyed by a soil scientist, knowledge of the geology can assist in soil mapping. Two different versions of the geology map layer were included in the upgraded PNGRIS. The first is the original geology layer containing the original lithological description used to produce the geological map. The second is the same geology layer reclassified into 'rock type', as it is rock type rather than geology which is of most use in agricultural planning.

4.2 Geology

4.2.1 Classification

The classification system used to describe the 1:250,000 scale geology maps, originally produced by Geoscience Australia (formerly Australian Geological Survey Organization), is presented in Appendix 2. There are more than 700 different lithological categories. The second classification system, 'Rock Type', groups each of the lithological categories into a simplified system with 25 classes that are described in table 14. The relationship between the 'rock type' classification and the original geology classification is shown in Appendix 2. The geology layer for PNG is shown in Figure 68, and the rock type layer for PNG is shown in Figure 69.

4.2.1.1 Rock type

The classification 'Rock Type' was adapted from Loffler (1974) and is based on simple criteria, such as origin, composition and grain size of parent material. These criteria are relevant to the interpolation of resource information, particularly soil properties, to unsurveyed parts of the country. The three main rock type categories recognized are sedimentary rocks, metamorphic rocks and igneous rocks.

Sedimentary rocks

Sedimentary rocks are subdivided into three groups on the basis of the degree of consolidation of materials, namely, consolidated, semi-consolidated, and unconsolidated sedimentary rocks.

Consolidated sedimentary rocks are differentiated on the basis of the predominance of carbonates into non-calcareous and calcareous rocks. Non-calcareous consolidated sedimentary rocks are further divided according to the predominant grain size, while the calcareous consolidated sedimentary rocks are subdivided according to the predominant composition.

The unconsolidated sedimentary rocks are subdivided into three classes on the basis of the processes involved in their formation.

Metamorphic rocks

Only consolidated metamorphic rocks are recognized and they are subdivided into three rock types according to the degree of metamorphism.

Igneous rocks

Igneous rocks are first differentiated on the basis of the degree of consolidation of materials: consolidated, semi-consolidated and unconsolidated igneous rocks. The consolidated igneous rocks are then differentiated on the basis of origin (that is, extrusive or intrusive), and predominant composition.

The classification of extrusive (volcanic) igneous rocks is difficult as their composition varies not only from one volcanic area to another, but also, within one volcanic centre, between individual lava flows. Consequently, the classification of volcanic rocks gives only an indication of the composition of the most commonly occurring rock type and does not take into account the range of composition.

In areas of comples geology where it is not possible to differentiate between the spearate rock types, two combined classes of consolidated igneous and sedimentary rocks are recognized.

Twenty five broad classes of rock type are differentiated and briefly described in Table 14. The code number associated with each rock type in Table 14 is the code used to identify that rock type in the GIS database.

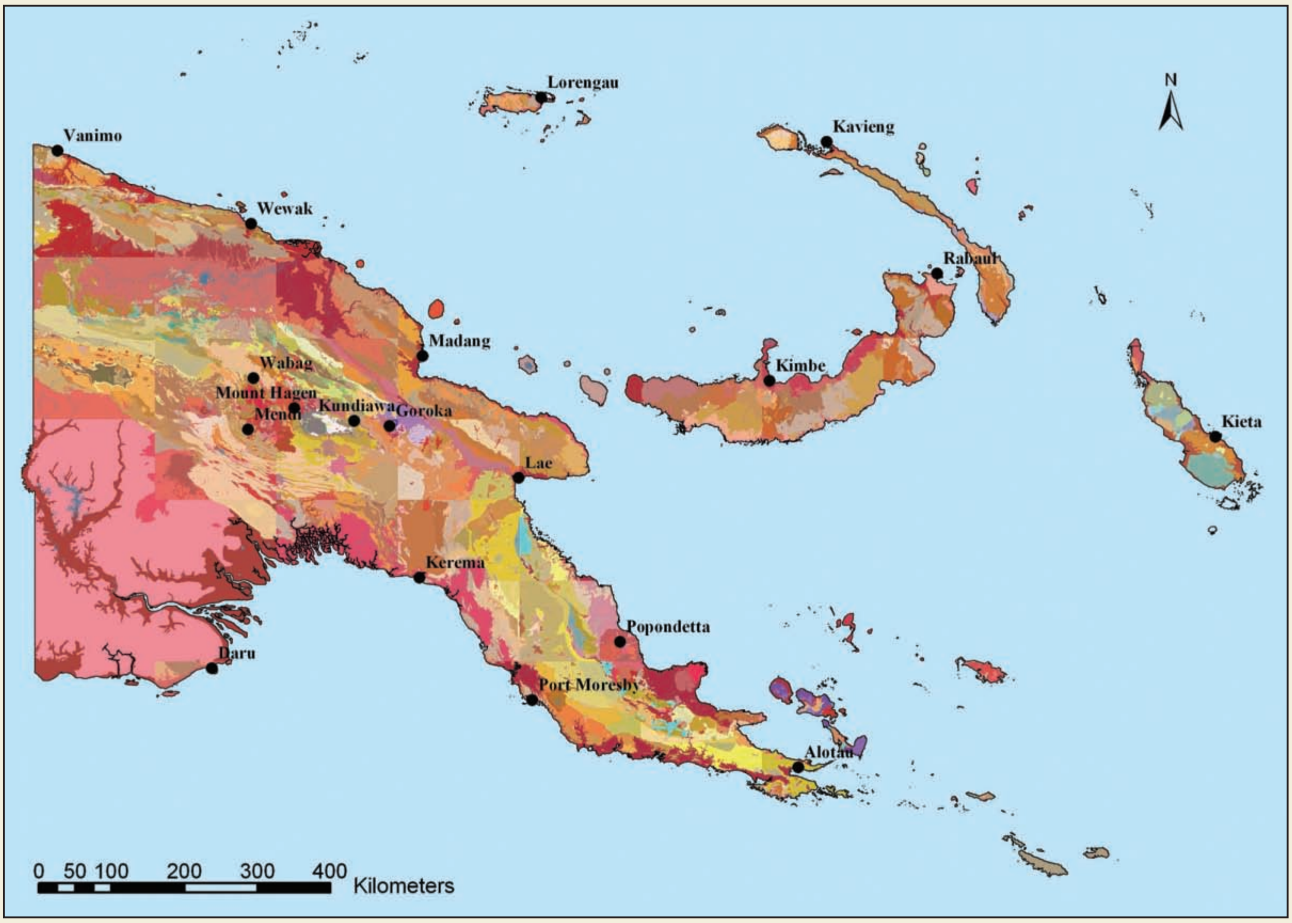


Figure 68: Geology layer for PNG.

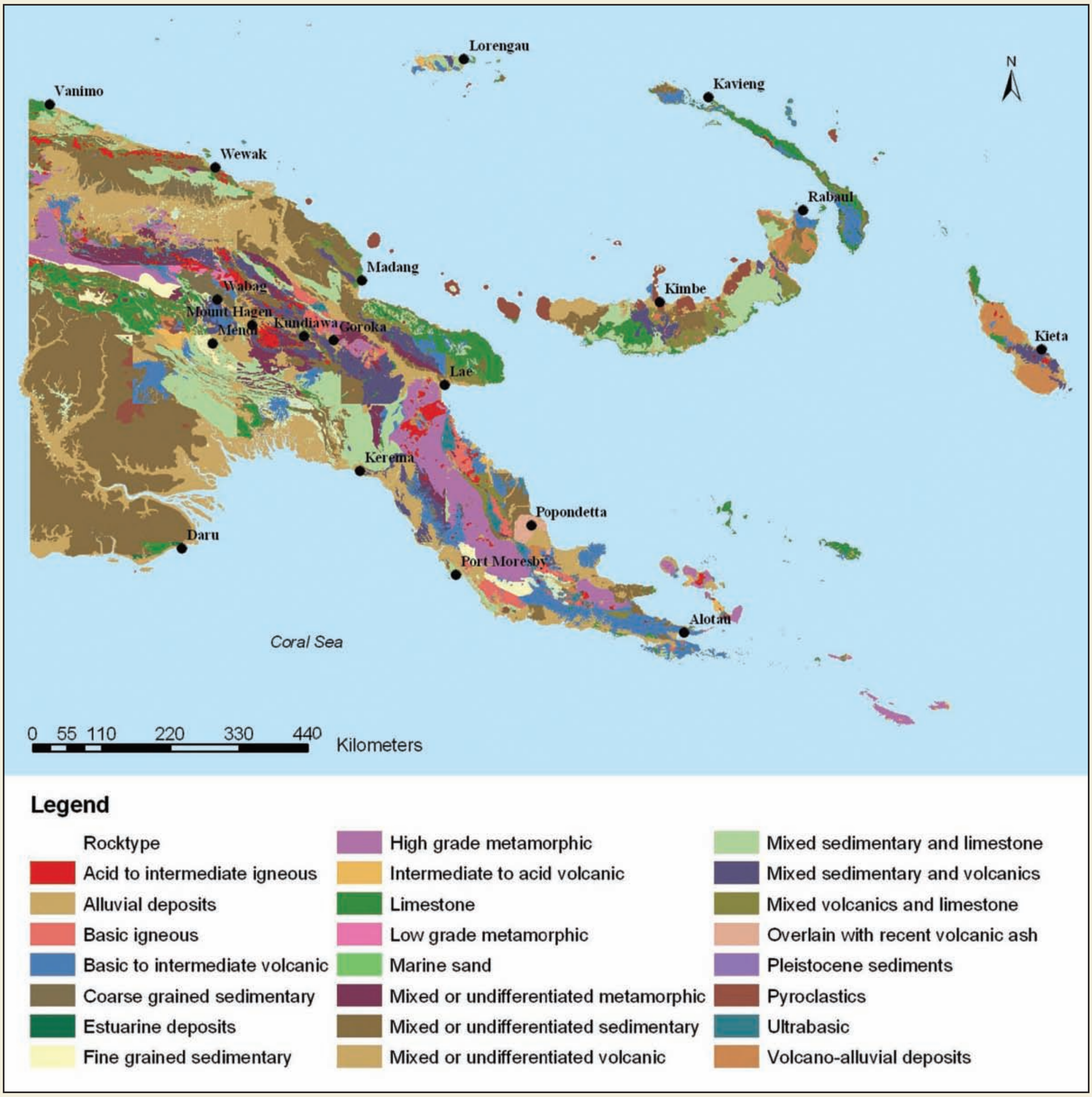


Figure 69: Rock type layer for PNG.

Table 14: Classification system for Rock Type

ROCK TYPE	CODE	DESCRIPTION
SEDIMENTARY ROCKS		
Consolidated non-calcareous		
Fine grained sedimentary	11	Mostly shale, siltstone, mudstone, and marl, which are composed of silt and finer grade particle sizes
Coarse grained	12	Mostly sandstone, greywacke and sedimentary conglomerate which are grade particle sizes
Mixed or undifferentiated	13	Includes either a mixture of fine to coarse sedimentary grained sedimentary rocks or the predominant grain size may be unknown
Consolidated calcareous		
Mixed sedimentary	14	Interbedded layers of limestone and and limestone (frequently calcareous) sedimentary rocks
Limestone	15	Consolidated sedimentary rocks high in carbonates but of variable grain size
Semi-consolidated		
Pleistocene sediments	40	Weakly consolidated fluvial or deltaic sediments of Pleistocene (or occasionally Pliocene) age and which are generally associated with relict landform types. These sediments are of variable texture, ranging from sandy clay deposits to boulder conglomerate, and generally deeply weathered
Unconsolidated		
Alluvial deposits	41	All detrital material of Recent age deposited by flowing water and/or gravity. They encompass fluviatile, colluvial (scree), lacustrine and alluvial fan deposits composed of sand, gravel, silt, mud, clay, or angular rock fragments
Marine sands	42	Accumulations of sediment, typically sand, deposited by wave action and modified by wind along a coastline
Unconsolidated		
Estuarine deposits	43	Mud, sand, silt, and clay sediments associate These sediments are predominantly fine grained and derived from material deposited by the interaction of fluvial and tidal processes and relatively strong wave-induced long shore currents
METAMORPHIC ROCKS		
Consolidated		
High grade metamorphic	21	Relatively coarse grained metamorphic rocks, such as schists, gneiss and amphibolites
Low grade metamorphic	22	Relatively fine grained metamorphic rocks, such as slates and phyllites
Mixed or undifferentiated metamorphics	23	Either a mixture of low to high grade metamorphic rocks or metamorphic rocks of unknown grade

ROCK TYPE IGNEOUS ROCKS	CODE	DESCRIPTION
Consolidated extrusive		
Mixed sedimentary and volcanics	30	Areas of complex lithology of sedimentary and volcanic igneous rocks or volcanolithic sediments
Basic to intermediate volcanic	31	Largely basalts, dolerites and andesites, which are fine grained volcanic rocks with relatively low silica content
Intermediate to acid volcanic	32	Mostly rhyolites and dacites, which are fine grained volcanic rocks with relatively high silica contents
Mixed or undifferentiated volcanic	33	Volcanic igneous rocks of either unknown or highly variable composition
Mixed volcanic and limestone	34	Areas of complex lithology of volcanic igneous rocks and limestone
Acid to intermediate igneous	35	Coarse grained igneous rocks with relatively high silica content, such as granites and granodiorites with some diorites and trachytes
Basic igneous	36	Coarse grained igneous rocks with relatively low silica content, such as gabbro and diorite
Ultrabasic	37	Peridotite, dunite, serpentine, pyroxene and metabasalts
Mixed or undifferentiated igneous	38	Areas of igneous rock of either highly variable or unknown chemical composition
Semi-consolidated		
Pyroclastics	46	All the fragmented volcanic material which has been blown into the atmosphere by explosive activity either liquid globules which solidify in the air or as solid fragments derived from the fracture of pre-existing rocks. The material is generally weakly consolidated and may be highly variable in character, ranging from fine grained (ash, tuff) to coarse grained (agglomerates, volcanic conglomerate), lahars (volcanic mudflows) and lava flows
Unconsolidated		
Volcano-alluvial deposits	45	Fluvially redistributed volcanic debris of consisting sand and gravel with minor silt and clay, and occasionally volcanic ash derived locally from recently active volcanoes
Overlain with recent ash	47	Unconsolidated fine grained material deposited as a result of recent (that is, within the last 10,000 years) volcanic explosions
Overlain with older ash	48	Unconsolidated fine grained material deposited as a result of older (more than 10,000 years) volcanic explosions

4.2.2 Data source and methods

The geology map included in the upgraded PNGRIS is a digitized version of Geoscience Australia's 1:250,000 geology maps. It was created as part of the BioRap project and was digitized by the Centre for Resource and Environmental Studies (CRES) at the Australian National University (ANU) (Nix et al, 2000). The digitized geology map had been converted to MapInfo vector format as part of the Biorap project. The geology and rocktype layers were reprojected into AGD84 geographics format and adjusted to match the PNG coastline.

4.2.3 Limitations

The BioRap geology layer adjusted for the PNGRIS upgrade was digitized from AGSO (now Geoscience Australia) geology maps. There are a number of inconsistencies in the geology maps across different mapsheets, as shown in Figure 70.

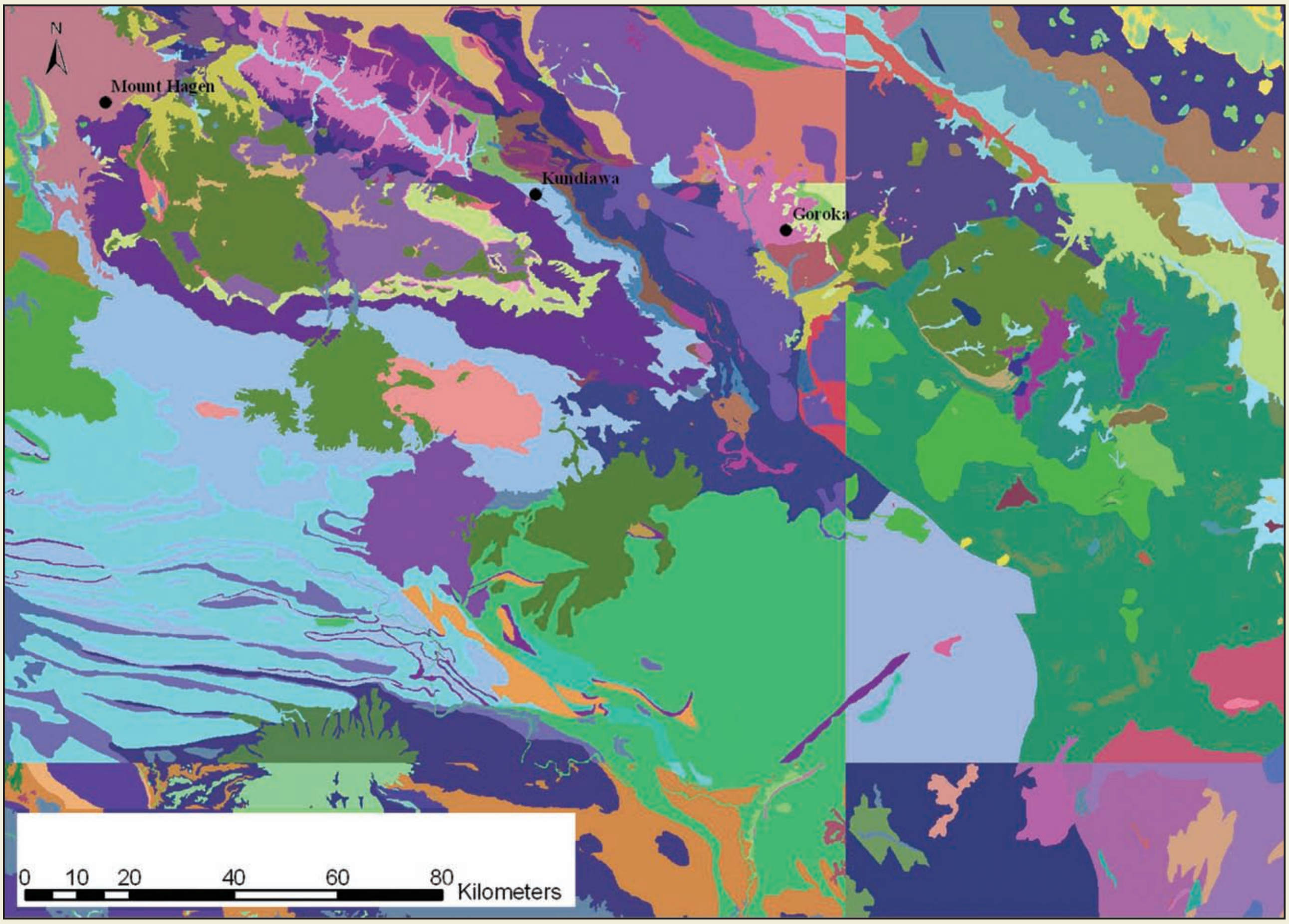


Figure 70: Inconsistencies in the geology layer. The straight line boundaries between adjacent geology types are the boundaries between adjacent mapsheets. Each mapsheet was produced separately. The straight line boundaries reflect different interpretations or classification systems being used in different mapsheets rather than actual differences in the geology.

5 Soil

5.1 General discussion

A polygonal soil map for PNG was created at the Great Soil Group level with one soil type per polygon, primarily as an input to the Papua New Guinea Land Evaluation System (PNGLES). PNGLES was created using the Cornell University's Automated Land Evaluation System (ALES) program (Rossiter & Wambeke, 1997). The soil map was made using the soil types and soil analytical data listed in each RMU contained in the previous version of PNGRIS.

The original RMU-based soil map was produced by extrapolating empirical soil measurements across the landscape using Jenny's (1941) approach to soil mapping, where soil is a function of climate, organisms (including humans), topographic factors, parent material and time. A maximum of three soil types and associated analytical data were assigned to the particular RMU in which the survey was conducted. RMUs without field survey plots were assigned the (up to) three soil types from the surveyed RMUs which were most similar in terms of climate, topography and geology.

The upgraded map of soils refines the RMU map by including more detailed topographic information in the spatial extrapolation of the empirical measurements of the soil. Each of the soil types and associated analytical data was extrapolated to a particular spatial location within the RMU using the topographic position layer described in section 2.3. The upgraded PNGRIS soil map is therefore a result of field surveys and spatial extrapolation based on climate, topography and geology.

The process by which each soil type in the previous RMU-based PNGRIS was assigned to each topographic position is outlined in section 5.4. The primary reason for requiring a soil map containing one soil type for each location in the landscape was as an input into the Automated Land Evaluation System (ALES), used by the Department of Agriculture and Livestock Land Use Section to produce maps of potential crop suitability in Papua New Guinea (see Appendix 1). However, the production of a soil map based on allocating a soil type to a topographic position comes with a number of limitations, which are discussed in sections 2.3.5 and 5.5.

5.2 Data sources

The soil types listed in the Resource Mapping Units (RMU's) contained in the previous version of PNGRIS and the UPNG DEM were the data sources used to produce the upgraded PNGRIS soil layer. The sources of the information used to produce the soil classification and soil attributes in each RMU are:

- analytical Data on PNG Soils (Bleeker & Healy, 1980);
- soils of PNG (Bleeker, 1983);
- CSIRO Land Research Series (1964-76) publications;
- reports made available by the Land Utilization Section of the PNG Department of Agriculture and Livestock (DAL).

5.3 Classification

Soil taxonomy and classification for the soil map contained in the upgraded PNGRIS GIS were undertaken at the USDA Great Soil Group level (USDA, 1975). The following section is taken, with some minor modification, from Bellamy & McAlpine (1995) and outlines each of the Great Soil Groups present in Papua New Guinea.

The following descriptions of each great soil group described in PNGRIS are given in the order shown in Table 15.

Table 15: Great soil groups identified in Papua New Guinea

Order	Suborder	Great group	Code	Distribution	Major previously named soil group
Entisols	Aquents	Cryaquents	110	Very local	Skeletal soils, Peat soils
		Sulfaquents	111	Common	Saline Peats and Muds, Mangrove soils
		Hydraquents	112	Very common	Young Alluvial soils, very poorly drained Alluvial soils
		Fluvaquents	113	Very common	Alluvial soils, Young Alluvial soils, Recent Alluvial soils
		Tropaquents	114	Very common	As for Fluvaquents
		Psammaquents	115	Common	Recent Alluvial soils
	Psamments	Tropopsamments	121	Common	Coarse textured Beach soils
		Ustipsamments	122	Very local	Coarse textured Beach soils
	Fluvents	Tropofluvents	131	Common	Young Alluvial soils, Recent Alluvial soils, coarse textured Beach soils
		Ustifluvents	132	Local	As for Tropofluvents
	Orthents	Troporthents	141	Very common	Lithosols, Skeletal soils, Slope soils
		Cryorthents	142	Very local	As for Troporthents
		Ustorthents	143	Very local	Colluvial soils
Histosols	Folists	Cryofolists	211	Very local	Alpine Peat and Humus soils
		Tropofolists	212	Common	Peat soils, Alpine Peat and Humus soils
	Hemists	Sulfihemists	220	Very local	Saline Peats and Muds
		Cryohemists	221	Very local	Alpine Peats and Humus soils
		Tropohemists	222	Common	Peat soils, Organic soils, Bog soils
	Fibrists	Cryofibrists	231	Very local	Alpine Peat and Humus soils
		Tropofibrists	232	Common	Peat soils, Organic soils, Bog soils
	Saprists	Troposaprists	241	Common	Peat soils, Organic soils, Bog soils

Order	Suborder	Great group	Code	Distribution	Major previously named soil group
Inceptisols	Aquepts	Halaquepts	311	Very local	Low Humic Gley soils, Alluvial soils
		Cryaquepts	312	Very local	Skeletal soils, Peat soils
		Andaquepts	313	Local	Humic Olive Ash soils, Unweathered Sandy Volcanic soils with black topsoils
		Tropaquepts	314	Common	Gleyed Plastic Heavy clay soils, Dark soils of Heavy Texture, Gleyed Pelosols
		Plinthaquepts	315	Very local	Gleyed Plastic Heavy clay soils
	Andepts	Cryandepts	320	Very local	Humic Brown Clay soils (on volcanic ash)
		Hydrandepts	321	Very common	Humic Brown Clay soils (on volcanic ash), Latosolic Andosols
		Eutrandepts	322	Very common	Moderately weathered Brown Ash soils
		Dystrandepts	323	Common	Moderately to little weathered Brown ash soils
		Vitrandepts	324	Very common	Unweathered Sandy Volcanic soils with black topsoil
		Durandepts	325	Very local	Brown Loams with an ash pan
	Tropepts	Humitropepts	331	Very common	Humic Brown Clay soils
		Ustropepts	332	Local	Brown Clay soils
		Eutropepts	333	Very common	Brown Forest soils, Dark Alluvial soils, Shallow Dark Clay soils, Reddish Clay soils
		Dystropepts	334	Very common	Strongly weathered Red and Brown Clay soils, Acid Red to Brown Clay soils, Acid Brown Forest soils, Uniform Red and Yellow Clays, Reddish Clay soils
	Ochrepts	Cryochrepts	341	Very local	Alpine Peat and Humus soils, Skeletal soils
	Umbrepts	Cryumbrepts	351	Very local	Alpine Peat and Humus soils, Skeletal soils
Vertisols	Uderts	Pelluderts	411	Local	Alluvial Black Clay soils, Black Earths, Grumusols
	Usterts	Pellusterts	421	Very local	Dark Cracking Clay soils, Grumusols
Mollisol	Aquolls	Argiaquolls	511	Local	Dull Meadow Podzolic soils, Meadow Podzolic soils
		Haplaquolls	512	Common	As for Argiaquolls but also poorly drained old Alluvial soils and Gleyed Pelosols
	Rendolls	N/A	520	Very common	Rendzinas, Limestone soils
	Ustolls	Natrustolls	531	Very local	Shallow Black Earths, Texture Contrast soils
		Calciustolls	532	Very local	Texture contrast soils, Brown clay soils
		Argiustolls	533	Very local	As for Calciustolls
	Ustolls	Haplustolls	534	Very local	Dark Cracking Clay soils, Beach soils
		Argiudolls	541	Common	Well drained Old Alluvial soils, Immature Brown soils on sedimentary rocks, Dull Meadow Podzolic soils, Meadow Podzolic soils
		Hapludolls	542	Very common	Young Alluvial soils, well-drained old Alluvial Black Clay soils

Order	Suborder	Great group	Code	Distribution	Major previously named soil group
Alfisols	Aqualfs	Albaqualfs	610	Very local	Meadow Podzolic soils
		Plinthaqualfs	611	Common	Meadow Podzolic soils, Meadow soils
		Tropaqualfs	612	Common	As for Plinthaqualfs but also Gleyed Plastic Heavy Clay soils and Weathered Gleyed soils
	Ustalfs	Natrustalfs	621	Very local	Textured Contrast soils
		Rhodustalfs	622	Very local	Alkaline Reddish Clay soils
		Haplustalfs	623	Local	Texture Contrast soils, Brown clay soils
	Udalfs	Natrudalfs	631	Very local	Brown Forest soils
		Rhodudalfs	632	Local	Terra Rossas
		Tropudalfs	633	Very common	Dull Meadow Podzolic soils, Brown forest soils, Immature brown soils on sedimentary rocks
Ultisols	Aquults	Paleaquults	710	Very local	Podzolized Gley Laterites, Lateritic and Gleyed Latosols
		Plinthaquults	711	Common	Meadow Podzolic soils, Podzolic Lateritic soils, Podzolized Gley Laterites
		Albaquults	712	Local	Meadow Podzolic soils, Lateritic and Gleyed Latosols
		Tropaquults	713	Common	Meadow soils, Meadow Podzolic soils, Gleyed Plastic Heavy Clay soils, Lateritic and Gleyed Latosols
	Humults	Palehumults	720	Local	Humic Brown Clay soils, Latosolic Andosols
		Tropohumults	722	Common	Humic Brown Clay soils, Humic mults Brown and Red Latosols, Strongly Weathered Red and Brown Clay soils
	Udults	Paleudults	730	Local	Lateritic soils, Podzolic Lateritic soils
		Plinthudults	731	Common	Red and Yellow Earths, Meadow Podzolic soils
		Rhodudults	732	Local	Acid Red to Brown Clay soils
		Tropudults	733	Common	As for Rhodudults but also Dull Meadow Podzolic soils
Oxisols	Humox	Haplohumox	811	Very local	Strongly weathered Red and Brown Clay soils
		Acrohumox	812	Very local	As for Haplohumox
	Orthox	Haplorthox	821	Very local	Acid Red to Brown Clay soils
		Eutrorthox	822	Very local	Granular Dark Red Uniform Heavy Clay soils

5.3.1 Entisols

Entisols are recently formed soils.

5.3.1.1 Aquents

Poorly drained to swampy alluvial soils, which do not have diagnostic horizons within 2m of the surface and the exchange complex is not dominated by amorphous material. They have either sulfidic material within 50cm of the mineral soil surface or are permanently saturated with water and typically have grey or bluish matrix colours.

110 Cryaquents are cold wet soils of the high mountains that have a mean annual soil temperature of less than 8°C.

111 Sulfaquents are Aquents that have sulfidic material within 50cm of the mineral soil surface. They are permanently saturated with water and normally associated with mangrove swamps and brackish water. Soil reaction is near neutral to alkaline but becoming extremely acidic after drainage.

112 Hydraquents are dominantly fine textured alluvial soils found near tidal estuaries and swamps. Bulk density is characteristically low and n-value is high (i.e. low soil strength).

113 Fluvaquents are poorly to very poorly drained alluvial soils typically found on the flood plains of the major rivers. Organic carbon content is relatively high (>0.2%) at least to a depth of 1.25m or decreases irregularly with depth.

114 Tropaquents are Aquents with low organic carbon contents and mottled grey colours. Mean annual soil temperature is 8°C or higher.

115 Psammaquents are sandy textured soils with grey or mottled grey colours.

5.3.1.2 Psamments

Well to imperfectly drained soils that have a texture of loamy fine sand or coarser to a depth of 1m to rock, whichever is shallower.

121 Tropopsamments are moderately well drained sandy soils that have some weatherable minerals. Mean annual soil temperature is 8°C or higher and the soils remain moist during most of the year.

122 Ustipsamments are moderately well drained sandy soils that have some weatherable minerals. Mean annual soil temperature is 8°C or higher and the soils are dry in some parts for less than 90 days (cumulative) in most years.

5.3.1.3 Fluvents

Well to imperfectly drained alluvial soils that have organic carbon contents which decrease irregularly with depth or remain above 0.2% to 125cm.

131 Tropofluvents are moderately well drained, stratified alluvials with textures of loamy fine sand or finer. Soil temperature is 8°C or higher and the soils remain moist during most of the year.

132 Ustifluvents are moderately well drained, stratified alluvials with textures of loamy fine sand or finer. The soils are dry in some or all parts for at least 90 days (cumulative) in most years.

5.3.1.4 Orthents

Soils without any diagnostic horizons formed on recent erosional surfaces. They overlie rock at 25cm or shallower or have loamy or finer textures in some horizon between the A horizon and a depth of 1m or rock surface. They occur on slopes greater than 25% (11°C) or have organic carbon contents that decrease regularly with depth or reach a level equal to or less than 2% at the 1.25m depth. Characteristics associated with wetness are absent.

141 Troporthents are Orthents that have mean annual soil temperature of 8°C or higher and the soils remain moist during most of the year.

142 Cryorthents are Orthents that have a mean annual soil temperature of less than 8°C.

143 Ustorthents are Orthents that have a mean annual soil temperature of 8°C or higher, and are dry in some or all parts for less than 90 days (cumulative) in most years.

5.3.2 Histosols

Histosols are peat soils

5.3.2.1 Folists

Organic (peat) soils that are never saturated with water for more than a few days and have rock, stones or boulders at a depth of less than 1m.

211 Cryofolists are freely drained soils of the high mountains with a mean annual soil temperature between 0° and 8°C.

212 Tropofolists are freely drained soils with a mean annual temperature of 8°C or higher.

5.3.2.2 Hemists

Moderately decomposed organic soils (peats) in which the botanic origin of two-thirds of the materials cannot be readily determined. They are permanently saturated with water and have a bulk density between 0.1 and 0.2gcm^{-3}.

221 Cryohemists are Hemists which have a mean annual soil temperature greater than 0°C but less than 8°C.

222 Tropohemists are Hemists with a mean annual soil temperature of 8°C or higher.

5.3.2.3 Fibrists

Little decomposed organic (peat) soils in which the plant remains are not easily destroyed by rubbing and their botanical origin can be readily determined. They are saturated with water for six months or more of the year.

231 Cryofibrists are Fibrists which have a mean annual soil temperature between 0^o and 8^oC.

232 Tropofibrists are Fibrists that have a mean annual soil temperature of 8^oC or higher.

5.3.2.4 Sapristss

Well decomposed organic soils (peats) in which the botanic origin of the material cannot be directly observed. They are permanently saturated with water, usually black, and have a bulk density of $>0.2gcm^{-3}$

241 Troposaprists are Saprists which have a soil temperature of 8^oC or higher.

5.3.3 Inceptisols

Inceptisols are moderately weathered soils without contrasting horizons.

5.3.3.1 Aquepts

Slightly to moderately weathered soils that have characteristics associated with wetness or a sodium saturation of 15% or higher in more than half of the soil to a depth of 50cm, and a water table within 1m of the surface at some time of the year.

311 Halaquepts are Aquepts that have a sodium saturation of 15% or higher.

312 Cryaquepts are cold wet soils of the high mountains that have a mean annual soil temperature between 0^o and 8^oC.

313 Andaquepts are Aquepts formed on volcanic ash having a low bulk density, black topsoils and mottled grey subsoils.

314 Tropaquepts are generally fine textured soils with dark topsoils and grayish mottled subsoils that have a mean annual soil temperature of 8^oC or higher.

315 Plinthaquepts are Aquepts that have plinthite that forms a continuous layer or constitutes 50% of the matrix in some sub-horizon within 1.25m of the surface.

5.3.3.2 Andepts

Moderately weathered, freely drained soils formed on volcanic ash and containing appreciable amounts of allophone that has a high exchange capacity. They have low bulk densities ($<0.85gcm^{-3}$) and lack the characteristics associated with wetness.

320 Cryandepts are cold soils of the high mountains that have a mean annual soil temperature between 0^o and 8^oC.

321 Hydrandepts are Andepts that have clays which dehydrate irreversibly into aggregates of silt, sand and gravel size.

322 Eutrandepts are Andepts that have a base saturation greater than 50% in some sub-horizon between 25cm and 75cm and are thixotropic in some horizons between 25cm and 1m.

323 Dystrandepts are similar to the Eutrandepts except that base saturation is less than 50% in all horizons between 25cm and 75cm.

324 Vitrandepts are little or unweathered Andepts that have gravelly or sandy textures and lack thixotropic properties, but moisture retention is higher than might be expected in soils with these textures.

325 Durandepts are Andepts that have a hardpan within 1m of the soil surface.

5.3.3.3 Tropepts

Relatively young moderately well drained soils which have a mean annual soil temperature of 8^oC or higher with less than 5^oC difference in mean temperature throughout the year. They have moderately high bulk densities ($>0.85gcm^{-3}$) and are low in amorphous clay minerals.

331 Humitropepts are Tropepts that have $>12kgm^{-2}$ organic carbon in the soil to a depth of 1m and less than 50% base saturation in some horizons between depth of 25cm and 1m.

332 Ustropepts are Tropepts that are dry in some part of the profile for at least 90 days (cumulative) in any year and have at least 50% base saturation in all horizons between 25cm and 1m in depth.

333 Eutropepts are Tropepts which have a base saturation of 50% or more in all horizons between depths of 25cm and 1m and do not dry out in all parts for more than 90 day (cumulative) in most years.

334 Dystropepts are Tropepts which have $< 12kgm^{-2}$ of organic carbon of soil to a depth of 1m or have a base saturation of less than 50% in some horizon between 25cm and 1m.

5.3.3.4 Ochrepts

Moderately well drained soils of cool high mountain areas with light coloured topsoils.

341 Cryochrepts are Ochrepts which have a mean annual soil temperature of less than 8^oC and do not have a duripan within 1m of the soil surface.

5.3.3.5 Umbrepts

Acid, dark coloured, freely drained and organic rich soils of cool high mountain areas.

351 Cryumbrepts are Umbrepts which have a mean annual soil temperature of less than 8°C and have less than 50% base saturation in some sub-surface horizon.

5.3.4 Vertisols

Vertisols are shrinking and swelling clay soils.

5.3.4.1 Uderts

Clay to heavy clay soils that have cracks which remain open for less than 90 days cumulative or are less than 1cm wide at a depth of 50cm.

411 Pelluderts are dark grey to black soils that have a chroma, moist, of less than 1.5 dominant in the matrix of all sub-horizons.

5.3.4.2 Usterts

Clay soils that have cracks that remain open for 90 days (cumulative) or more in most years and typically occur in strongly seasonal climates.

421 Pellusterts are dark grey to black soils that have a chroma moist, of less than 1.5 dominant in the matrix of all sub-horizons.

5.3.5 Mollisols

Soils with thick dark base rich topsoils.

5.3.5.1 Aquolls

Poorly to very poorly drained soils with gleyed and/or prominently mottled subsoils.

511 Argiaquolls are Aquolls which have coarser textured surface horizons and a mean annual soil temperature which is 8°C or higher.

512 Haplaquolls are similar to the Argiaquolls but lack the coarser textured surface horizons.

5.3.5.2 Rendolls

Shallow soils formed in humid regions on calcareous parent material which have a less than 50cm thick dark surface horizon, directly overlying rock or partly decomposed, disintegrating material.

520 Rendolls are so similar that they have not been subdivided into great groups.

5.3.5.3 Ustolls

Moderately well drained soils which are found in areas with strongly seasonal climates. Ustolls are dry in some or all parts of the soil for at least 90 days (cumulative) in most years.

531 Natrutolls are Ustolls which have coarser textured surface horizons and high exchangeable sodium content.

532 Calciustolls are Ustolls which have a high accumulation of either calcium carbonate, calcium and magnesium carbonate or gypsum within 1m of the soil surface

533 Argiustolls are Ustolls which have coarser textured surface horizons.

534 Haplustolls are Ustolls that lack either coarser textured surface horizons, or high exchangeable sodium content, or the accumulation of carbonates or gypsum in the upper 1m of the soil profile.

5.3.5.4 Udolls

Moderately well drained soils found in humid climates. Mean annual soil temperature is 8^{o}C or higher and the soil profile does not dry out for more than a total of 90 days (cumulative) in any year. Calcium rich horizons are absent in the top 50cm.

541 Argiudolls are Udolls that have coarser textured surface horizons.

542 Hapludolls are Udolls that lack coarser textured surface horizons.

5.3.6 Alfisols

Soils with coarser textured surface horizons and base rich subsoils.

5.3.6.1 Aqualfs

Poorly to very poorly drained soils showing characteristics associated with wetness, namely, mottles or iron-manganese concretions, or a chroma of 2 or less immediately below the topsoil.

610 Albaqualfs are Aqualfs that have an abrupt textural change and a bleached A2 horizon.

611 Plinthaqualfs are Aqualfs that have plinthite that forms a continuous layer or constitutes 50% of the matrix in some sub-horizon within 1.25m of the surface.

612 Tropaqualfs are Aqualfs that have a mean annual soil temperature of 8^{o}C or higher.

5.3.6.2 Ustalfs

Moderately well drained soils that have a mean annual soil temperature which is 8^{o}C and the soil is dry in some or all parts for 90 days (cumulative) or one in most years.

621 Natrustalfs are Ustalfs that have high exchangeable sodium content.

622 Rhodustalfs are Ustalfs that have a subsoil which throughout its thickness has a colour hue redder than 5YR, and a value, moist, of less than 4.

623 Haplustalfs are Ustalfs that lack high exchangeable sodium content and the prominent red colours of the other great soil groups.

5.3.6.3 Udalfs

Moderately well drained soils of humid climates that have a mean annual soil temperature of 8°C or higher and the soil does not dry out in some or all parts for more than 90 days (cumulative) in most years.

631 Natrudalfs are Udalfs that have high exchangeable sodium content.

632 Rhodudalfs are Udalfs that have a subsoil which throughout its thickness has a colour hue redder than 5YR, a colour value, moist, of less than 4.

633 Tropudalfs are Udalfs that at a depth of 50cm have less than 5°C difference in mean summer and mean winter soil temperature.

5.3.7 Ultisols

Soils with coarser textured surface horizons and subsoils with low base saturation.

5.3.7.1 Aquults

Poorly to very poorly drained soils that are saturated with water at some time of the year and have a chroma, moist of 2 or less together with mottles or iron-manganese concretions. Mean annual soil temperature is 8°C.

710 Paleaquults are Aquults with relatively uniform textured subsoils in which the clay content does not decrease by more than 20% from its maximum within 1.5m of the surface.

711 Plinthaquults are Aquults which have plinthite which forms a continuous layer or constitutes more than half the matrix within 1.25m of the surface.

712 Albaquults are Aquults that have an abrupt textural change and a bleached A2 horizon.

713 Tropaquults are Aquults that have a mean annual soil temperature of 8°C or higher.

5.3.7.2 Humults

Moderately well drained, humus-rich soils that have a mean annual soil temperature which is 8°C or higher.

720 Palehumults are Humults with relatively uniform textured subsoils in which the clay content does not decrease by more than 20% from its maximum within 1.5m from the surface.

721 Plinthohumults are Humults that have plinthite that forms a continuous layer or constitutes at least 50% or more of the volume of some sub-horizon within 1.25m of the surface.

722 Tropohumults are Humults that at a depth of 20cm have less than 5°C difference between mean summer and mean winter soil temperatures.

5.3.7.3 Udults

Moderately well drained, humus-poor soils found in humid climates. Mean annual soil temperature is 8°C or more and the soil does not dry in some or all parts for more than 90 days (cumulative) in most years.

730 Paleudults are Udults with relatively uniform textured subsoils in which the clay content does not decrease by more than 20% from its maximum within 1.5m from the surface.

731 Plinthudults are Udults that have a plinthite that forms a continuous phase or constitutes more than 50% of some horizon within the upper 1.25m of soil.

732 Rhodudults are Udults that have a surface horizon with a colour value, moist, of less than 4 and a subsoil that has a colour value, dry, of less than 5.

733 Tropudults are Udults that have less than 5°C difference in mean soil temperatures throughout the year.

5.3.8 Oxisols

Strongly weathered soils with a very low subsoil cation exchange capacity.

5.3.8.1 Humox

Well drained, humus rich soils with a very low subsoil cation exchange capacity.

811 Haplohumox are Humox that have a subsoil cation exchange retention capacity of more than 1.5meq per 100g of clay.

812 Acrohumox are Humox that have in some part of the subsoil a cation retention capacity of less than 1.5meq per 100g clay.

5.3.8.2 Orthox

Well drained soils that have (within 2m of the soil surface) a mean annual soil temperature of 8°C or less and the soil does not dry out in any part for more than 90 days (consecutive).

821 Haplorthox are Orthox that have a cation retention capacity of greater than 1.5meq per 100g clay and a base saturation of less than 35% in some part of the subsoil.

822 Eutrorthox are Orthox that have a cation retention capacity of greater than 1.5meq per 100g clay and a base saturation of greater than 35% in some part of the subsoil.

5.4 Method

The soil map in the upgraded PNGRIS was created by allocating each of the (up to) three soil types listed in each of the RMUs contained in the previous version of PNGRIS to a topographic position within that RMU. Soil mapping staff at the Land Use Section in the Department of Agriculture and Livestock in conjunction with a soils expert systematically allocated each soil type listed in each of the 4837 RMUs to a topographic position in the topographic position layer described in section 2.3. The soil type assigned to each topographic position in each RMU is called ‘Soil_A’ in the table attached to the soils map, and the code describing Soil_A is called ‘SoilA_code’ (see Table 16). Each soil shown in the map (that is each ‘Soil_A’) has a range of chemical and physical properties associated with it which are included in the table attached to the soils map. The chemical and physical properties associated with each soil assigned to each topographic position are listed and described fully in section 5.6.

Decisions regarding which soil type contained in each RMU should be allocated to which topographic position were made with reference to the soil association work of Bleeker (1983), knowledge and experience of DAL staff, knowledge and experience of a consulting soil expert (Graham Tyrie), field observation, other available soil maps, and the landform map of Papua New Guinea described in section 2.6. The topographic position layer was then intersected with the RMU map in the ESRI Arcinfo GIS. The soil type and soil analytical data for each soil type in each RMU was then attached to each polygon representing a topographic position in each RMU. A soil map showing one soil type at the Great Soil Group level per unit area defined as a topographic position within an RMU was then produced. The upgraded PNGRIS soil map for PNG is shown in Figure 71.

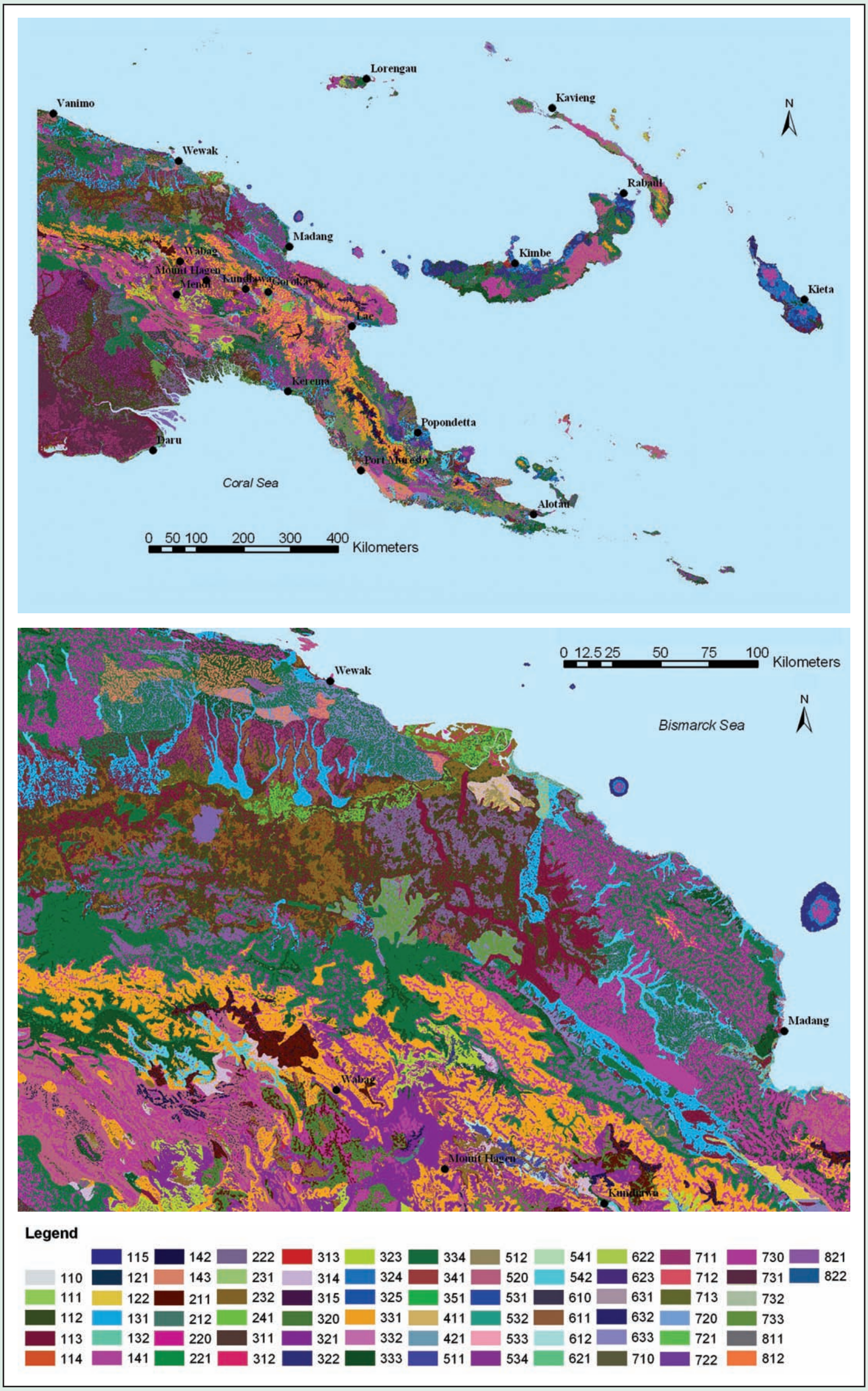


Figure 71: The upper image shows the soil map for the whole of PNG made using the topographic position map and the RMU-based soil map. The lower image shows a close-up view of the soil map in the East Sepik, Madang and Highlands region in northern PNG.

5.5 Limitations

A soil map containing one soil per location in the landscape was made primarily for use in the PNG version of ALES, which is used to produce crop suitability maps (see Appendix 1). However, many more soil types occur in the landscape than are captured by the PNGRIS data, and there can be a rapid change in soil characteristics within a very small distance which are not captured by a soil map only showing a maximum of three soil types in each land mapping unit (RMU). In the table attached to the map, columns have been included called 'Soil_B', 'Soil_C' and 'Soil_D'. In places where it was known to DAL land use section staff that a particular soil type occurred in the landscape which was not listed as one of the those included in the RMU, this soil type is included in the 'Soil_B', 'Soil_C' or 'Soil_D' columns. However, chemical and physical data were only available for soils included in the RMU's. It is therefore important to note that the chemical and physical properties associated with each soil type refer only to 'Soil_A'. As and when field survey data becomes available, the soils map can be readily edited to assign each of the soils (if any) listed in the Soil_B, C, and D columns to their appropriate location.

Soil surveys have not been conducted at every location in PNG and field checking of the soil map has been undertaken only in several areas in Milne Bay and Central Provinces. There are many places where the soil type shown in the PNGRIS soil map is a best estimation based on available field surveys and the topographic information contained in the topographic position map. However, as and when new soil surveys are conducted, the PNGRIS soil layer can be readily edited to include more accurate field survey measurements. The limitations associated with the topographic position map described in section 2.3.5 also need to be considered when using the soil layer.

5.6 Soil attributes

5.6.1 Introduction

Soil attributes used to distinguish 'Great Soil Group' classes (USDA, 1975) are often inadequate by themselves for meaningful land evaluation for agricultural uses. Consequently, for each great soil group described, an additional data set of 15 soil attributes is provided. These soil attributes are listed in Table 16 and are grouped into physical and chemical properties. This additional soil information is required for matching crop requirements to land characteristics for land evaluation in the Papua New Guinea Land Evaluation System (see Appendix 1). It also provides soil information at a level more readily understood by planners not familiar with Soil Taxonomy.

A description of the soil attributes attached to the soil map is presented in Table 16 through to Table 39.

Table 16: Soil attributes attached to each polygon representing a great soil group in the upgraded PNGRIS soil map

Soil attribute	Description	Soil property
Soil A	Primary great soil group class (all chemical, physical, and composite properties refer to Soil A)	Soil Great Group
Soil B	Secondary great soil group class (if there is one)	
Soil C	Third great soil group class (if there is one)	
Soil D	Fourth great soil group class (if there is one)	
Soil A code	Code describing Soil A (see section 5.3)	
Stoniness	Stoniness of soil	Physical
Depth	Effective soil depth	
Texture 1	Texture of the topsoil (0-25cm)	
Texture 2	Texture of the subsoil (25-100cm)	
Drainage	Soil drainage	
Available water holding capacity 1	Available water holding capacity of topsoil (0-25cm)	
Available water holding capacity 2	Available water holding capacity for mid-horizon (25-50cm)	
Available water holding capacity 3	Available water holding capacity for subsoil (50-100cm)	
Erodibility	Soil erodibility	
Cation exchange capacity	Cation exchange capacity	Chemical
Base saturation	Base saturation	
Nitrogen	Percentage Nitrogen in the soil	
Available Phosphorous (P)	Available phosphorous	
Exchangeable Potassium (K)	Exchangeable Potassium (K)	
Anion fixation	Anion fixation	
Mineral reserves	Soil mineral reserves	
Soil pH	Soil reaction	
Salinity	Electrical conductivity	
Fertility	General fertility	Composite
Inherent fertility	Inherent fertility	

5.6.2 Data sources

The principal data source for these soil attributes is the site data collected during the CSIRO land resource surveys (1952-72). These data have been compiled in the form of a compendium of Analytical Data of PNG Soils (Bleeker & Healy, 1980). In addition, use has been made of soil analytical data collected by the Land Utilization Section of the Department of Primary Industry, Port Moresby (now the Land Use Section in the Department of Agriculture and Livestock).

5.6.3 Method

Where available, soil attribute descriptors are derived directly from the sources referred to in Section 5.6.2. For those areas without field observation or analytical data, the soil attribute descriptors were derived, using the database, through extrapolation of soil data from other areas with similar environmental characteristics (such as climate, rock type, landform, vegetation) and modified by field experience. The process of allocating soil attributes to the landscape was originally done using the old RMU-based version of PNGRIS. To facilitate spatial extrapolation, as well as data storage, the values for each attribute were classified, and class codes are used in the database as attribute descriptors. Although extrapolation may be subject to errors, corrections to the database can be easily made whenever site information becomes available.

The code number associated with each soil attribute descriptor in Sections 5.6.4 and 5.6.5, and 5.6.6 below is the code used to identify that descriptor in the database.

5.6.4 Physical properties

5.6.4.1 Stoniness/rockiness

The presence of stones and/or rocks on the surface or upper 30cm of the soil is mainly of importance with regards to limitations to mechanical clearing or use of other agricultural machinery. For subsistence farmers using manual labour, only high percentages of stones/rocks (Classes 4 or 5 in Table 17) are likely to seriously affect yields due to the reduced volume of soil exploitable to plants, and hence water and nutrient availability.

The classification for the stoniness/rockiness attribute used in the inventory is given in Table 17.

Table 17: Stoniness/rockiness classification

Code	% stones/rocks[1]	Description
1	<1	Not stony/rocky
2	1 – 3	Slightly stony/rocky
3	3 – 15	Moderately stony/rocky
4	15 – 30	Very stony/rocky
5	>30	Extremely stony/rocky
	[1]On the surface or in the upper 30cm of the soil	

5.6.4.2 Effective soil depth

The effective soil depth classification used in the inventory is given in Table 18. The effective soil depth is defined as the thickness of soil above a layer of restricting root growth (e.g. consolidated rock or cemented materials, such as gravel).

Table 18: Effective soil depth classification and codes

Code	Soil depth	Description
1	>100	Deep
2	50 – 100	Moderately deep
3	25 – 50	Moderately shallow
4	<15 – 30	Shallow

Most annual crops have a rooting depth of about 50cm, while for tree crops the rooting system can reach beyond 150cm. However, most crops produce good yields in soils with an effective soil depth of about 100cm and this value has been used as an upper limit.

Soil depth, in conjunction with rainfall and soil texture, has an important influence on water availability to plants and hence crop yields.

5.6.4.3 Soil texture

The soil field texture classification used in the inventory is given in Table 19.

Modified by clay mineralogy, structure and organic matter content, the soil texture reflects the physical properties of the soil. Texture classes (Table 19) are provided in the inventory for both topsoil (0-25cm), referred to as ‘Texture 1’, and subsoil (25-100cm) referred to as ‘Texture 2’, and are largely based on field textures. If hard rock is encountered within 25cm, this is indicated by a separate class in the subsoil (Class 6), otherwise subsoil values are indicated by the prevailing texture. For example, if a soil has 20cm of clay loam over 60cm of friable clay, the texture codes are 2 and 3 for topsoil and subsoil respectively; similarly if a soil has 40cm of friable clay over hard rock the codes are 3 and 3; but if a soil has 20cm of friable clay over hard rock the codes are 3 and 6.

Table 19: Soil field texture classification and codes

Code	Class	Description
1	Coarse	Sands, loamy sands, gravels[1]
2	Medium	Sandy loam, loam, silt loam, silt, silty clay loam, sandy clay loam, clay loam, organic mud
3	Fine	Clay[2], silty clay[2], sandy clay[2]
4	Very fine	Heavy clay, silty heavy clay, sandy heavy clay, clay[3], silty clay[3], sandy clay[3]
5	Peats	Mucks, peats 'something' peat on peaty mucks
6	Rock	Massive rock or cemented material that cannot be augored
	[1]Soils having textures described as a variety of gravel (e.g. gravelly clay) should be downgraded by one class. For instance, a gravelly clay (with a friable consistence) will be coded as class 2 (i.e. medium texture).	
	[2]Refers to soils with high friability in relation to clay content and/or having a granular or sub-angular blocky structure.	
	[3]Refers to soils which are massive or very weakly structured and dominated by 1:1 clay minerals. These soils most commonly have a plastic or very sticky and non-porous consistency. Typical examples are Vertisols, heavy textured alluvial soils (Entisols), or soils developed on fine grained sediments (e.g. Tropaquepts).	

5.6.4.4 Soil drainage

The soil drainage classification used in the inventory is given in Table 20.

Table 20: Soil drainage classification and codes

Code	Drainage
1	Well drained
2	Imperfectly drained
3	Poorly to very poorly drained
4	Waterlogged (swampy)

This classification of soil drainage is based on the degree and depth of gleying of the soil. The standard procedure is to commenced at the top of the soil profile and then determine the degree of gleying using the criteria outlined in Table 21.

Table 21: Determining the degree of gleying

Degree of gleying	Criteria
None	No mottling and matrix chromas of 3 or more in a hue of 5Y or redder, if values are more than 3; or mottling with chromas of 4 or more in mottles as well as matrix
Weak	Common to many mottles with chroma 2-3 in matrix with chroma 4 or more; or matrix with hues redder than 2.5Y with chromas of 2-3 and common to many mottles with chromas of 4 or more; or common grey mottles (at 10YR4/1 in brownish reddish matrix)
Moderate	Many grey mottles in brownish to reddish matrix or matrix 10YR4/1-8/1, 2.5Y4/2-8/2 or 5Y4/2-8/2 with or without brown mottles; or, if no matrix, grey mottles more than combined percentage of brown and red mottles
Strong	Matrix N4/0-N7/0, 5Y4/1-8/1, or any other colour on the Munsell gley colour chart

The assessment of the soil drainage condition is then based on the first horizon encountered in the profile with either weak, moderate or strong gleying, using Table 22.

Table 22: Soil drainage class (on sites with ground water gleying) as determined by the degree and depth of gleying

Degree of gleying[1]	Depth in cm at which gleying commences			
	<25	25 – 50	50 – 100	100 – 150
Strong	4	3	2	2
Moderate	3	3	2	1
Weak	3	2	2	1
None	1	1	1	1
	[1]Assessed using Table 21			

The soil drainage class determined using Table 22 refers to the soil drainage attribute codes of the inventory as outlined in Table 20.

In sandy soils the depth of the water table may also be a very useful indicator of drainage conditions. For the assessment of the degree of gleying, topsoils coloured dark by organic matter (A1 horizons) should be ignored in most cases.

5.6.4.5 Available water holding capacity

The codes and descriptors for available water holding capacity classification used in the inventory are given in Table 23.

Table 23: Classification of available water holding capacity (AWC)

Code	Class	AWC (cm)
1	Very high	>15
2	High	10–15
3	Moderate	5–10
4	Low	3–5
5	Very low	<3

Soil available water capacity (AWC) is the amount of water held in the soil between tensions corresponding to field capacity (FC) and permanent wilting point (PWP). Although the AWC gives a reasonable approximation of the total amount of soil water available for crop growth, its significance to agriculture emerges only in relation to climatic data.

In order to distinguish between shallow, moderately deep and deep rooting crops the AWC has been calculated for three depth zones: 0-25cm (AWC1), 0-50cm (AWC2), and 0-100cm (AWC3). In the inventory, five major classes of AWC are recognized (Table 23).

Estimates of the AWC are obtained for each of the depth zones by summation of separate estimates for the various textural horizons. This is determined by multiplying the value obtained in Table 24 by the thickness of the horizon and dividing by 100. The figures given in Table 24 are based on the USDA Soil Survey Manual (1951, inch/feet converted into cm).

Table 24: Assessment of AWC from soil texture

Class	Description	AWC (cm/m)
Coarse	Gravel Sand Loamy sand	14 7 9
Medium	Sandy loam Silt Loam, silt loam, sandy clay loam Silty clay loam, clay loam, organic mud	13 15 16 17
Fine	Clay, silty clay, sandy clay (with high friability in relation to clay content)	15
Very fine	Clay, heavy clay, silty heavy clay, sandy heavy clay (with massive, plastic and sticky to very sticky consistency)	12
Peaty (organic)	Muck or well decomposed peat, ‘Something’ peat 20[2] Moderately decomposed peat Peat raw	20 15 10

[1]When soil texture is described as a variety of gravel (e.g. loamy gravel) use AWC value of the variety and halve its AWC value (e.g. loamy gravel = 16/2 = 8cm/m)

[2]When well or moderately decomposed peat; but if raw peat, halve texture value of the mineral fraction and add 5cm/m (e.g. loamy peat = 16/2 = 13cm/m)

In soils having textures with peaty prefix (e.g. peaty loams), a value of 4 should be added to the texture value given in Table 24. In soils having horizons described as being 'organic' (e.g. organic loam), or having high topsoil organic matter content (e.g. Humitropepts and Hydrandepts), a value of 2 should be added to the texture value for the 0-25cm layer.

The AWC estimates are thus based on considerations of both the texture and the organic matter content only, without taking the site drainage condition of the soil into account. Consequently, given that the texture and organic matter content are the same, a poorly drained sandy soil will have the same AWC as a well drained sandy soil.

5.6.4.6 Soil erodibility

The provisional grouping of soils according to their soil erodibility risk in Table 25 refers to great soil groups found in similar topographic positions. This table is largely derived by taking the texture of the surface horizon and organic matter content into account.

Table 25: Provisional grouping of some major soil groups according to their soil erodibility risk

Code	Class	Great soil group		Description
1	Very low	Histosols Hydrandepts Dystrandepts Eutrandepts	Vitrandepts Cryandepts Andaquents Humitropepts	Soils with high to very high organic matter content and moderate to rapid permeabilities. Granular to fine crumby surface horizons. Some lowland Andepts may have moderate very fine sand and silt contents
2	Low	Argiudolls Hapludolls Rendolls Argiaquolls Haplaquolls Argiustolls Haplustolls Calciustolls Cryumbrepts Durandepts	Rhodudalfs Rhodustalfs Psammaquents Tropopsamments Ustipsamments Tropohumults Plinthohumults	Except for sandy Entisols, these soils have moderate organic matter content and moderate permeabilities. The sandy Entisols have generally low organic matter content and are rapidly permeable and structure-less
3	Moderate	Cryaquepts Tropaquepts Cryochrepts Dystropepts Eutropepts Ustropepts Cryaquents Hydraquents Sulfaquents Fluvaquents Tropaquents	Tropofluvents Ustifluvents Cryorthents Ustorthents Troporthents Tropaqualfs Tropudalfs Haplustalfs Rhodudults Haplohumox Acrohumox	Generally slowly permeable soils with moderate organic matter content; the alluvial Entisols have low to moderate organic matter content, are massive and may have moderate very fine sand and silt content
4	High	Pelluderts Pellusterts Halaquepts Albaqualfs Natrustalfs Natrudalfs Plinthaqualfs	Natrustolls Plinthaquults Albaquults Plinthudults Tropaquults Haplorthox Eutrorthox	*Vertisols*: very slowly permeable, often subject to surface scaling and have prismatic or coarse blocky structures, but moderate organic matter content. *Ultisols and Alfisols*: generally relatively low organic matter content and relatively high very fine sand and silt content. Poorly structured topsoils

5.6.5 Chemical properties

5.6.5.1 Cation exchange capacity

The cation exchange capacity (CEC) is a measure of the soil's ability to retain cations against downward leaching and thus reflects the nutrient retention capacity of a soil. Three classes of CEC (Table 26) are recognized in PNGRIS.

Table 26: Classification of the cation exchange capacity (topsoil only) and codes

Code	Class	ECEC (meq %)	CEC (meq %)
1	High	>10	>25
2	Moderate	5 – 10	10 – 25
3	Low	<5	<10

The CEC was assessed for the topsoil (0-25cm) layer only. It was derived by extracting cations from the soil with solutions buffered and pH 7.0 and 8.2. In many tropical soils the charge (CEC) is pH dependent, and a determination at these pH values may considerably overestimate the actual values. In such cases, the 'effective' CEC (ECEC), which is the CEC measured with an unbuffered salt at or near the actual field pH, is a much more useful parameter. Unfortunately, very few ECEC data are available for PNG soils. Therefore CEC values based on the NH4OAc extraction method at pH 7.0 have been used here. However, where available, ECEC values are used in preference.

5.6.5.2 Base saturation

Base saturation (BS) is an expression of the quantity of cations available for plant growth in relation to the cation exchange capacity (CEC). As for the CEC classification, BS values are grouped into three classes (Table 27).

Table 27: Base saturation classification and codes

Code	Class	Base saturation (%)
1	High	>60
2	Moderate	20 – 60
3	Low	<20

Vegetation obtains most of its nutrients from the surface horizon(s). Consequently, to determine the BS value for each soil, the mean BS values for the topsoil (0-25cm) depth zone were multiplied by two (2) and added to the mean BS value of the subsoil (25-100cm). The resulting value was then divided by three (3) and then the appropriate BS class determined from Table 27.

5.6.5.3 Percentage total nitrogen

Three classes of percentage total nitrogen (Table 28) are recognized in PNGRIS.

Table 28: Percentage total nitrogen classification and codes

Code	Class	Percentage total nitrogen%
1	High	>0.5
2	Moderate	0.2 – 0.5
3	Low	<0.2

As most of the nitrogen occurs in the surface (A) horizons in combination with organic matter, percentage total nitrogen is assessed for the topsoil (0-25cm) zone only. Of the three major soil elements (N, P and K), total nitrogen is generally the most poorly correlated with plant growth and subject to rapid changes following forest clearing and cropping.

A high nitrogen value will usually indicate a high organic matter content. Therefore a separate classification for organic matter is not included in the inventory. Organic matter and nitrogen levels in PNG soils are high for tropical soils (that is, usually greater than 4% organic matter in the 0-15cm layer).

5.6.5.4 Available phosphorous

Three available phosphorous classes (Table 29) are distinguished in PNGRIS.

Table 29: Available phosphorous classification and codes

Code	Class	Available P (ppm)
1	High	>20
2	Moderate	10 – 20
3	Low	<10

Data on available phosphorous in PNG soils are very limited and general conclusions on soil phosphorous content are thus very difficult to make. In general, Oxisols, Ultisols, and Andepts have low available P content, while most recent alluvial soils (Fluvents and Fluvaquents) have moderate to high content.

The available P classification of a soil for PNGRIS was determined by adding the mean available P value of the topsoil (0-25cm) layer multiplied by 2, to the mean value of the subsoil (25-100cm) and dividing the resulting value by 3.

5.6.5.5 Exchangeable potassium

Three classes of exchangeable potassium (Table 30) are distinguished in PNGRIS.

Table 30: Exchangeable potassium classification and codes

Code	Class	Exch.K (meq %)
1	High	>0.6
2	Moderate	0.2 – 0.6
3	Low	<0.2

The exchangeable potassium level of a soil was determined for PNGRIS by adding twice the mean value of the topsoil (0-25cm) layer to the mean value of the subsoil (25-100cm) and dividing the resulting value by three.

In contrast to nitrogen and phosphorous, the potassium distribution in soil generally follows a pattern which is related to:

1. The presence/absence of potassium-bearing mineral such as micas and K-feldspars
2. The degree of weathering of the soil.

Clay rich soils dominated by 2:1 clay minerals (mostly Entisols and Mollisols) usually have high exchangeable K content. Highly weathered soils characterized by kaolinite or Al/Fe hydroxides in the clay fraction (mostly Oxisols, Ultisols and strongly weathered Dystropepts) generally have low exchangeable potassium content.

5.6.5.6 Anion fixation

Three classes of anion fixation (Table 31) are distinguished in PNGRIS.

Table 31: Anion fixation classification and codes

Code	Class	P-retention (%)	C/N ratio
1	Low	<60	<14
2	Moderate	60 – 90	14 – 25
3	High	>90	>25

Anion fixation attempts to delineate soils with high phosphorous (P) fixation capacities or a low rate of nitrogen mineralization. While P fixation is most prevalent in soils characterized by amorphous clay minerals, soils with very high organic matter content are likely to have very low nitrogen mineralization rates in view of their high C/N ratios. In such soils, determinations of N or P content alone are, therefore, insufficient for the assessment of the nitrogen or phosphorous status. For instance, a soil which is considered deficient in P on the basis of measurement of available P may be relatively easily corrected by small fertilizer applications. However, because of its very high phosphate buffering capacity, another soil with the same level of available P may require vast amounts of P fertilizer to produce the same concentration of P in the soil solution. It is therefore, important to assess the available phosphorous and total nitrogen contents of soils in conjunction with their possible anion fixation levels.

5.6.5.7 Mineral reserve

Three broad classes of mineral reserve (Table 32) are distinguished in PNGRIS.

Table 32: Mineral reserve classification and codes

Code	Class	Description
1	High	High CEC values (generally >25meq %); high reserve of feldspars, amphiboles and pyroxenes; clay mineral fraction dominated by 2:1 minerals
2	Moderate	Moderate CEC values (generally 10-25 meq %); moderate mineral reserve (10 to 40% weatherable minerals); clay mineral fraction mixture of 2:1 and 1:1 minerals
3	Low	Low CEC values (generally <10 meq %) low mineral reserve (<10% weatherable minerals); clay mineral fraction dominated by 1:1 minerals and/or (hydr)oxides (e.g. Goethite, gibbsite)

In contrast with cation exchange capacity classification, the mineral reserve as a general guide is assessed for the subsoil (depths of 25-100cm) only, using:

- cation exchange capacity;
- per cent weatherable minerals in the 0.05 – 0.25mm sand fraction;
- clay mineralogy.

If undecomposed rock is encountered at shallow depth the mineral reserve is assessed to be high. In general, young alluvial soils (Entisols) or recent volcanic ash soils (Andepts) will have high mineral reserves, while Oxisols and Pale-great soil groups will have generally low mineral reserves.

The mineral reserve of a soil is an important characteristic related to the soil's 'natural' fertility. Except for soils with a positive charge, which are rare in PNG, a low mineral reserve will seldom render a soil unsuitable for cultivation. The mineral reserve influences the soil's long term productivity, because it reflects the presence or absence of potential plant nutrients and it also influences the available water content. It is of particular importance to subsistence farmers because they generally apply very few, if any, fertilizers.

5.6.5.8 Soil reaction

The classification for soil reaction used in PNGRIS is outlined in Table 33.

Table 33: Soil reaction (pH) classification and codes

Code	Class	Soil reaction (H_2O)	
		1:5	1:1
1	Weakly acid to neutral	6.0 – 7.0	5.5 – 6.5
2	Acid	5.0 – 6.0	4.5 – 5.5
3	Strongly acid	<5.0	<4.5
4	Alkaline	7.0 – 8.0	6.5 – 7.5
5	Strongly alkaline	>8.0	>7.5

The pH of a soil is defined as the negative logarithm of the hydrogen-ion concentration. In water with an H-ion concentration of 10-7 moles/litre, the pH equals 7 (neutral). The more acid the soil, the higher the H-ion concentration. A pH value of less than 5 indicates that a very low supply of bases (such as N, K, Ca) in the soil necessitates the application of fertilizers.

The pH is also used in the inventory as an indicator of possible levels of aluminium toxicity, as virtually no analytical data are available on extractable aluminium in PNG soils. Therefore, soils with a pH (H_2O 1:5) between 5.0 and 6.0 or <5.0 (Table 33) are assumed to have aluminium toxicity problems with an aluminium saturation of 10 to 60% or >60% respectively. Strongly alkaline soils with a pH (H_2O 1:5) or >8.0 may have problems related to phosphorous and/or iron fixation and certain trace element deficiencies, such as zinc. While the pH of the whole soil profile should be taken into account, pH values of the upper part should be considered the most important.

In the database, a weight of two (2) was given to the mean pH of the topsoil (0-25cm) layer, and of one (1) to the mean pH of the subsoil (25-100cm) layer, and the resulting sum divided by 3. If the only available data are field pH, determination values for the 1:1 paste should be followed in (Table 33) to identify the soil reaction class.

5.6.5.9 Salinity

The salinity attribute is described by three major classes (Table 34) in PNGRIS.

Table 34: Classification of salinity

Code	Class	Salinity (conductivity in mmhos cm^{-1})
1	None	<4
2	Weak	4 – 8
3	Moderate to strong	>8

The description of the salinity attribute is derived largely from environmental conditions because very little information on salinity levels is available for PNG soils. The environmental indicators include vegetation of salt or brackish water environments (e.g. mangroves), and columnar structure and/or high pH levels observed in the field in soils found in areas of low seasonal rainfall.

5.6.6 Composite properties

5.6.6.1 General fertility

General fertility of the soil is described by four classes (Table 35) in PNGRIS.

Table 35: Classification system for general fertility of the soil

Code	General fertility
1	High
2	Moderate
3	Low
4	Very low

Soil general fertility ratings are based on five attributes, namely Cation Exchange Capacity (CEC), Base Saturation (BS), total Nitrogen (%N), Phosphorous (Av.P) and Potassium (K). As a first step CEC and BS are combined in a more general rating as shown in Table 36.

The next step involves combining the general CEC, BS class with individual ratings for N, P and K into a general fertility rating. Table 37 shows the relationship when an equal weighting for each attribute is assumed.

Table 36: Combining CEC and BS in a general rating

CEC	BS	General Rating
High	High	High
High	Moderate	Moderate
Moderate	High	Moderate
Moderate	Moderate	Moderate
Moderate	Low	Low
Low	Moderate	Low
Low	Low	Low

Table 37: Assessment of General Fertility Rating

Ratings for CEC/BS, N, P and K	Overall Rating
High, High, High, High	High (1)
High, High, High, Moderate	High (1)
High, High, High, Low	Moderate (2)
High, High, Moderate, Moderate	Moderate (2)
High, High, Moderate, Low	Moderate (2)
High, High, Low, Low	Moderate (2)
Moderate, Moderate, Moderate, High	Moderate (2)
Moderate, Moderate, Moderate, Moderate	Moderate (2)
Moderate, Moderate, Moderate, Low	Moderate (2)
Moderate, Moderate, High, Low	Moderate (2)
Low, Low, Moderate, High	Low (3)
Low, Low, Moderate, Moderate	Low (3)
Low, Low, Low, High	Low (3)
Low, Low, Low, Moderate	Very low (4)
Low, Low, Low, Low	Very low (4)

5.6.6.2 Inherent fertility

There are three classes (Table 38) of inherent soil fertility listed in PNGRS. Inherent fertility is the ability of the soil to 'restore' itself after the protective topsoil has been eroded. It is assessed by combining the ratings for mineral reserve and the effective soil depth. This is because the mineral reserve is basically the soil's 'natural' fertility, as assessed from the percentage weatherable minerals and cation exchange capacity (CEC) values of the subsoil. Combined with the depth of the soil this will influence the rooting ability of plants and hence the potential to take up soil nutrients. The assessment of the inherent fertility is shown in Table 39.

Table 38: Classification of Inherent fertility

Code	Inherent fertility
1	High
2	Moderate
3	Low

Table 39: Combining mineral reserve and soil depth into an inherent fertility rating

ATTRIBUTE		Inherent Fertility
Mineral Reserve	**Soil Depth**	
High (1)	Deep (1)	High (1)
High (1)	Moderate Deep (2)	Moderate (2)
High (1)	Shallow (3)	Low (3)
High (1)	Very Shallow (4)	Low (3)
Moderate (1)	Deep (1)	High (1)
Moderate (1)	Moderate Deep (2)	Moderate (2)
Moderate (1)	Shallow (3)	Low (3)
Moderate (1)	Very Shallow (4)	Low (3)
Low (3)	Deep (1)	Moderate (2)
Low (3)	Moderate Deep (2)	Low (3)
Low (3)	Shallow (3)	Low (3)
Low (3)	Very Shallow (4)	Low (3)

As can be expected most soils in the PNGRIS soil map will have either a high or moderate inherent fertility. This is because PNG is a relatively young country with few highly weathered landforms having soils with low mineral reserves. However, shallow and very shallow soils are fairly common on steeply sloping terrain, particularly at higher altitudes on hard rocks.

6 Population

6.1 Introduction

The population layer contained in the PNGRIS upgrade shows points representing each of the locations, referred to as census units, surveyed in the 2000 PNG census. The population layer contains the name and location of the census unit, the province, district and local level government region in which the census unit lies, as well as the total population of the census unit, as well as the number of males and females in the census unit. The population layer is shown in Figure 72.

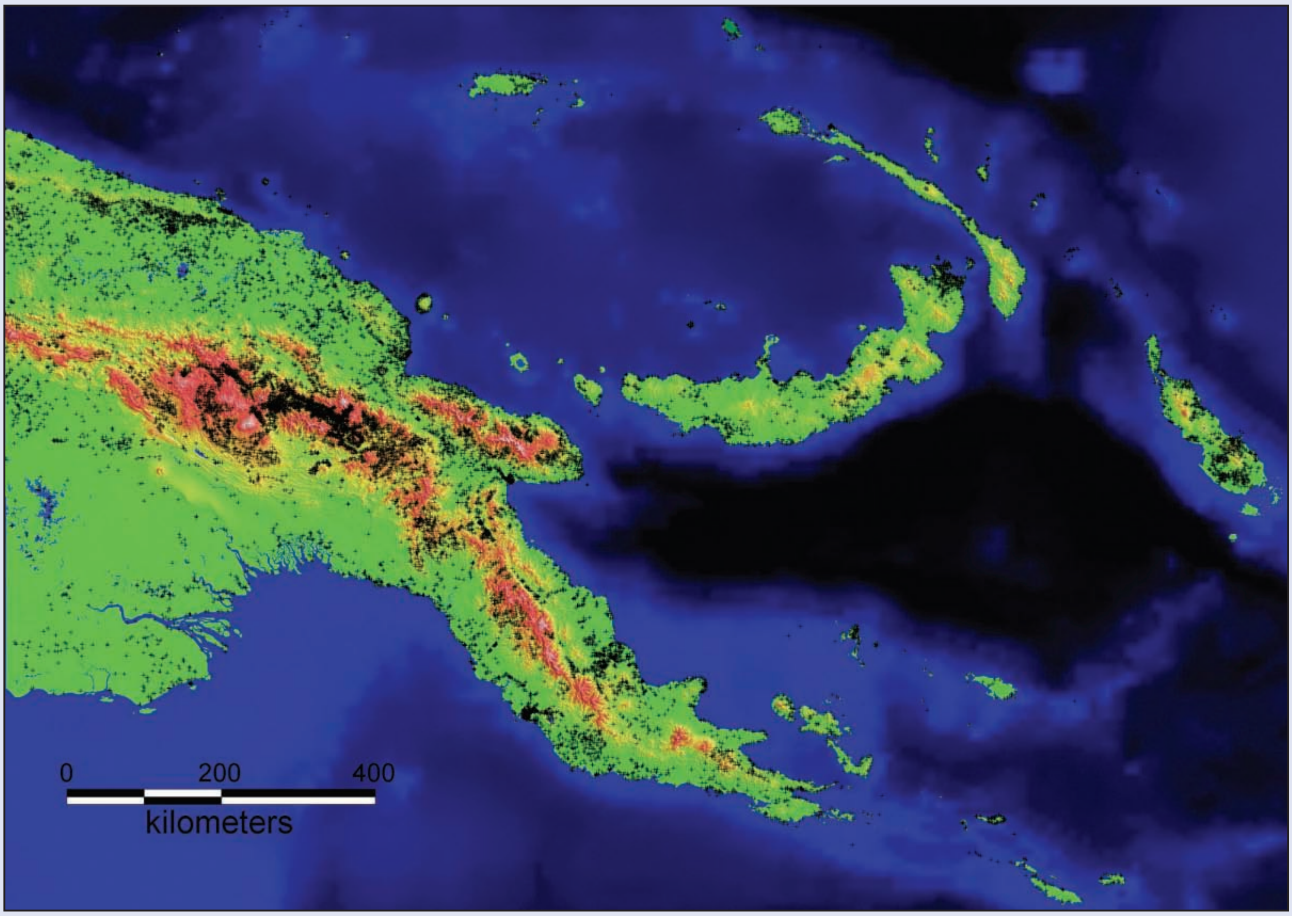


Figure 72: The population layer for the PNGRIS upgrade. Each point represents the location of each census unit surveyed during the 2000 census, and has a table attached listing the number of people living in that unit.

6.2 Data source and methods

The population layer included in the PNGRIS upgrade comes from the census conducted in 2000 by the government of Papua New Guinea. The PNG Bureau of Statistics population data was compiled into a MapInfo layer by the PNG National Mapping Bureau.

7 Inundation

7.1 Introduction

Inundated or flooded lands refer to areas that are permanently or temporarily under water or waterlogged. They may result from overland flow/run on, stream overflow, ponding from excessive rainfall or tidal influence. Inundation estimates are described by type, frequency and duration of inundation/flooding according to the system developed in the previous version of PNGRIS and outlined in Bellamy & McAlpine (1995).

7.2 Classification

Eight classes of inundation are differentiated in the inventory classified by type, frequency and duration of inundation/flooding as outlined in Table 40.

Table 40: Classification of type, frequency and duration of inundation

Code	Inundation class	Description
0	No flooding or inundation	
1	Waterlogged	Areas with only very little or no standing water at the surface but with a soil profile that is saturated either permanently or for time periods in excess of six months
2	Periodic brief flooding	Areas which are generally flooded for 3 to 4 days or less as a result of brief river flooding overflow or short term flooding and ponding due to intensive rainfall events.
3	Long term inundation	Areas which are inundated for periods of up to 4 to 6 months but inundation is shallow (<0.25m) and subject to drying out for short periods. Usually restricted to the wet season or to areas with high ‘dry’ season rainfall
4	Seasonal inundation	Areas that are seasonally inundated to a moderate (>0.25m) or greater depth and which do not dry out
5	Near permanent	Areas that are seasonally inundated in the wet season and subject to long term inundation during the dry season but can occasionally dry out
6	Permanent inundation	Areas that are permanently inundated usually to a considerable depth
7	Tidal flooding	Areas subject to tidal flooding. Normally associated with mangroves
8	Tidal flooding with freshwater inundation	Areas subject to both tidal flooding and inundation as a result of river flooding with restricted estuarine conditions

The inundation layer included in the PNGRIS upgrade is shown in Figure 73.

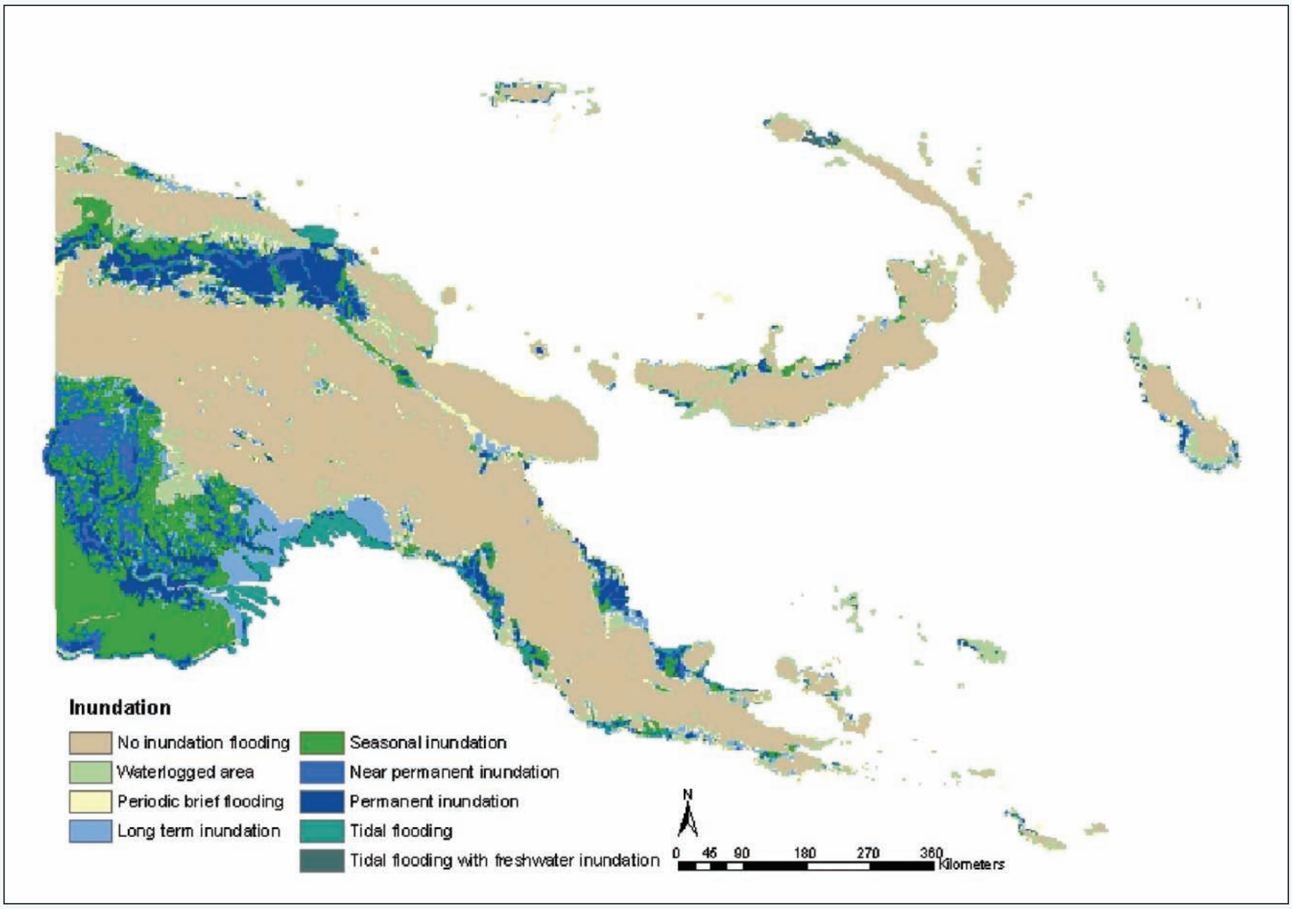


Figure 73: Inundation classification of PNG.

7.3 Data sources

Direct data on inundation in Papua New Guinea are limited. As will be seen below, the estimation of inundation status relied heavily on vegetation and landform as a surrogate. For this reason the inundation information presented must be treated as an approximation.

The inundation classification was estimated using the inundation classification in the previous RMU-based version of PNGRIS which was based on:

- landform, vegetation and climatic attributes;
- the PNG 1:100,000 Topographic Survey series of maps;
- limited field survey observations made during CSIRO land resource surveys between 1952-72.

This inundation classification was then further refined using:

- the upgraded PNGRIS slope map;
- the upgraded PNGRIS topographic position map.

7.4 Method

The previous RMU-based version of PNGRIS generated inundation classes primarily on the basis of the vegetation, landform (see section 29) and climate information that was contained in each RMU. Where field data on the inundation/flooding status of an area were not available, the inundation attributes for each RMU were inferred from a consideration of the vegetation type (Paijmans, 1975) in conjunction with landform and climatic attributes. Typical vegetation types associated with major levels of inundation are outlined in Table 41.

Table 41: Vegetation types typically associated with the major inundation types

Inundation type		Vegetation type
1	Long term inundation	Open forest, small crowned forest on plains and fans
2	Seasonal inundation	Open forest, swamp woodland, swamp forest
3	Near permanent inundation	Swamp woodland, swamp forest, swamp grassland, herbaceous swamp vegetation
4	Permanent inundation	Swamp woodland, swamp forest, swamp grassland, herbaceous swamp vegetation
5	Tidal flooding	Mangroves, swamp woodland
6	Tidal flooding with freshwater inundation	Swamp woodland, mangroves

Ratings for inundation status for each RMU were based primarily on landform and vegetation, as discussed in Bellamy & McAlpine (1995). Inundation status according to each landform type is outlined in Appendix 3.

In the previous RMU-based version of PNGRIS, only one type of inundation was assigned to each RMU. As indicated above, in practice more than one type may occur and the type may change seasonally. The inundation classification in the RMU-based map was refined for the PNGRIS upgrade using the upgraded slope and topographic position maps outlined in sections 2.4 - 2.3 to broadly approximate the land elements listed in Appendix 3. Inundation class in the PNGRIS upgrade was thereby assigned on the basis primarily of vegetation, landform and an approximation of land elements.

7.5 Limitations

Landforms, as defined by the RMU-based landform map outlined in section 26, subject to inundation and/or flooding (such as swamps, lakes, alluvial or estuarine plains, beach swales) frequently grade into each other and may change their inundation status through time, making classification difficult and terms such as ‘permanent’ and ‘seasonal’ imprecise. For example, lakes frequently grade into swamps at their margins, and many floodplains include both permanently and seasonally inundated parts depending on the distance to the main stream, the presence or absence of levees or other barriers, and local drainage and climatic conditions. Some large swamps may contain permanent or near permanent areas of open water, while other swamps receive runoff from adjacent areas and consequently are subject to marked water table fluctuations, particularly in the dry season. Inundation classes assigned on landform, land element, and vegetation should therefore be treated as an approximation.

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Appendix 1

8 PNGLES crop suitability assessment

8.1 Introduction

The climatic, soil and topographic information contained in the previous RMU-based version of PNGRIS, in combination with the Automated Land Evaluation System (ALES, Rossiter & Wambeke, 1997), is used by the Land Use Section in DAL to produce maps of potential crop suitability. Using the upgraded PNGRIS data, it is now possible to enter more detailed climatic, topographic and soil information into ALES to produce better crop suitability maps. An example of a crop suitability map produced using the upgraded map layers compared to that produced using the previous RMU-based system is shown in Figure 74.

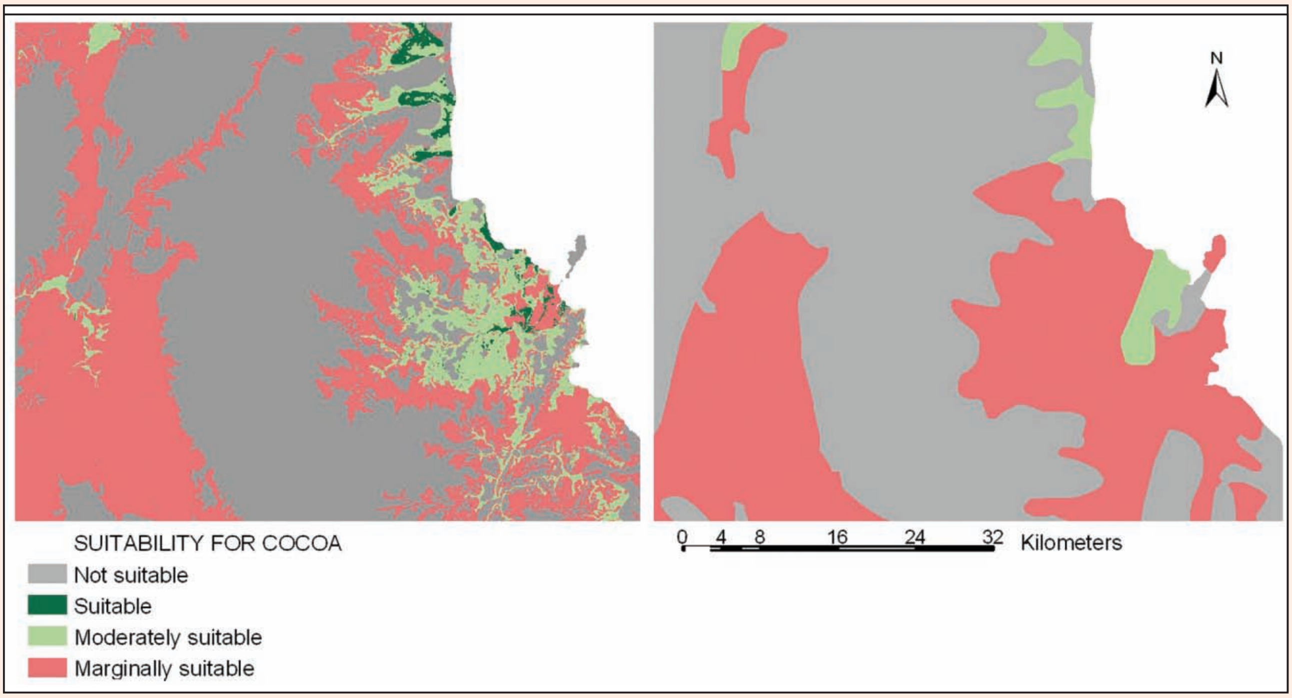

Figure 74: Suitability map for cocoa (low capital input) in Morobe Province created using the upgraded PNGRIS layers on the left, and the RMU-based map on the right.

ALES also has the capacity to show the reasons why areas in the landscape were rated as suitable or not suitable for a particular crop, as shown in Figure 75.

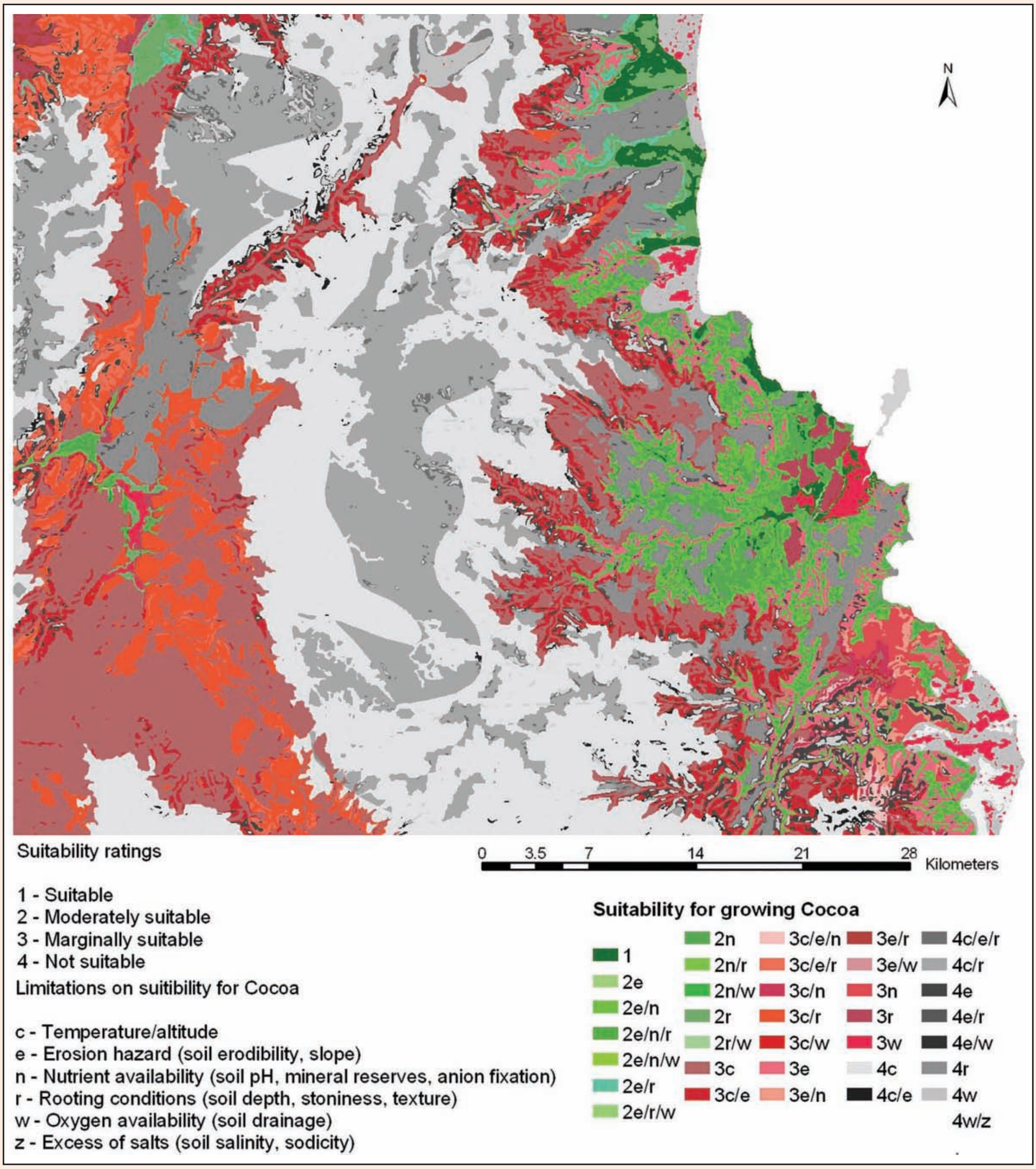

Figure 75: Suitability map for cocoa in SE Morobe Province showing the limitations for growing cocoa as defined by PNGLES.

The following pages contain a worked example and step by step guide showing how to use the upgraded PNGRIS layers and ALES to produce a crop suitability map.

8.1.1 System and data requirements for ALES crop suitability maps

Two pieces of software and three datasets need to be installed to construct a crop suitability map using ALES:

1. MapInfo (or another GIS such as ArcGIS).
2. The Automated Land Evaluation System (ALES) program.
3. PNGLES. PNGLES refers to the settings applied to the ALES program which were designed for PNG. PNGLES also contains a database of crop requirements for 18 crops.
4. The upgraded climatic, topographic and soil PNGRIS layers listed in Table 42, and described in sections 2 - 5 of this document.

ALES can be downloaded free from Cornell University's land evaluation web page (http://www.css.cornell.edu/landeval/ales/ales.htm). The PNGLES dataset is contained in the 'PNGLES' directory on the 2007 upgraded PNGRIS dataset, and can be imported directly into ALES.

8.1.2 Producing a crop suitability map

The steps involved in producing a crop suitability map using the upgraded PNGRIS datasets and PNGLES are:

1. Reclassifying the PNGRIS layers to be compatible with the PNGLES system.
2. Intersecting the separate climatic, topographic and soil layers to produce a single map layer with a single table attached listing values for each climatic, topographic and soil layer.
3. Running a comparison between the table attached to the intersected PNGRIS layers and the PNGLES crop requirement data using ALES.
4. Attaching the output of Step 3, a suitability table, to the intersected PNGRIS layer to view the suitability table as a crop suitability map.

The following section firstly gives a brief outline of PNGLES, and then presents a detailed discussion of the steps involved in using PNGLES (see section 8.2) and the upgraded PNGRIS layers to construct a suitability map.

8.2 PNGLES

The version of ALES adapted for PNG is called the Papua New Guinea Land Evaluation System (PNGLES). PNGLES produces crop suitability maps by comparing a database of the climatic, topographic and soil characteristics required by a particular crop, with a database of climatic, topographic and soil characteristics of the landscape being assessed. Places in the landscape which have the same soil, topographic and climatic characteristics as those required by a given crop are rated as suitable for that crop. Places which do not have the appropriate climate, soil or topographic characteristics are rated as unsuitable. PNGLES therefore firstly needs the input of a database containing the climatic, soil and topographic characteristics required by crops, and secondly a database containing the climatic, soil, and topographic characteristics occurring in the land being assessed. A full discussion of how ALES and PNGLES works is given in Rossiter & Wambeke (1997) and Venema & Daink (1992). A database of crop requirements for 18 crops is compiled in the PNGLES dataset, which is supplied in the PNGRIS upgrade along with the upgraded PNGRIS layers. A list of the soil, climatic and topographic characteristics that PNGLES requires are presented in Table 42.

Table 42: Climatic, topographic and soil layers required by PNGLES to produce crop suitability maps

Information required by PNGLES	Dataset
Climate	Mean annual rainfall
	Rainfall seasonality
Topography	Elevation
	Slope
	Landform
Soil	Soil type
	Soil Mineral reserves
	Soil pH
	Soil depth
	Soil texture of upper horizon
	Soil texture of lower horizon
	Soil salinity
	Soil anion fixation
	Stoniness of the topsoil/upper horizon
	Soil cation exchange capacity
	Soil drainage

As part of the PNGRIS upgrade DAL Land Use Section and UPNG Remote Sensing Centre adapted the previous version of PNGLES, described by Venema & Daink (1992) to facilitate the input of the more detailed datasets described in sections 2 - 5 of this document. The upgraded PNGLES is contained in the 'PNGLES' directory in the PNGRIS upgrade dataset.

PNGLES requires the input of the climatic, topographic and soil characteristics described in Table 42, but only allows a maximum of 16 classes for each attribute. Many of the climatic, topographic and soil layers contained in the upgraded version of PNGRIS contain more than 16 classes (refer to sections 2 - 5). In order to use PNGLES to produce crop suitability maps, the upgraded PNGRIS climatic, topographic and soil datasets required by PNGLES (Table 42) must be reclassified. Discussions between DAL Land Use Section staff and PNG agriculture experts resulted in the production of a classification system for each dataset designed to produce the most detailed maps for the most agriculturally productive regions. The classification system for each dataset required as an input to PNGLES is described below:

8.2.1 Climatic attributes

Rainfall PNGLES class	Rainfall range
1	1000 – 1250
2	1250 – 1500
3	1500 – 1750
4	1750 – 2000
5	2000 – 2250
6	2250 – 2500
7	2500 – 2750
8	2750 – 3000
9	3000 – 3250
10	3250 – 3500
11	3500 – 3750
12	3750 – 4000
13	4000 – 5000
14	5000 – 6000
15	6000 – 7000
16	>7000

Rainfall Seasonality PNGLES class	PNGRIS seasonality class
1	<100mm – >200mm; >200mm dominant (large range)
2	<100mm – >200mm; <100mm dominant (large range)
3	100 – 200mm to >200mm (moderate range)
4	<100mm to 100 – 200mm (moderate range)
5	All months >200mm (no seasonality)
6	All months 100 – 200mm (no seasonality)

8.2.2 Topographic attributes

Elevation PNGLES class	Elevation range (m)
1	0 – 200
2	200 – 300
3	300 – 400
4	400 – 500
5	500 – 600
6	600 – 800
7	800 – 1000
8	1000 – 1200
9	1200 – 1400
10	1400 – 1600
11	1600 – 1800
12	1800 – 2000
13	2000 – 2300
14	2300 – 2600
15	2600 – 2900
16	>2900

Slope PNGLES class	Slope PNGRIS classes (degrees)
1	0
2	0 – 2
3	2 – 5
4	5 – 10
5	10 – 15
6	15 – 20
7	20 – 25
8	25 – 30
9	30 – 35
10	>35

8.2.3 Soil attributes

Table 43: PNGLES great soil group code

PNGLES Soil type class	PNGRIS soil code	PNGRIS great soil group
1	111	Sulfihemists
2	220	Sulfihemists
3	531	Natrustalfs
4	532	Calciustolls
5	621	Natrustalfs
6	631	Natrudalfs
7*	0*	Other great groups
* PNGRIS contains many more soil classes; too many to be included in PNGLES		

Table 44: PNGLES Stoniness code

PNGLES stoniness class	PNGRIS % stones and rocks	PNGRIS description
1	<1	Not stony/rocky
2	1 – 3	Slightly stony/rocky
3	3 – 15	Moderately stony/rocky
4	15 – 30	Very stony/rocky
5	>30	Extremely stony/rocky

Table 45: PNGLES soil depth code

PNGLES depth class	PNGRIS soil depth (cm)	PNGRIS description
1	> 100	Deep
2	50 – 100	Moderately deep
3	25 – 50	Shallow
4	15 – 30	Very shallow

Table 46: PNGLES drainage code

PNGLES drainage class	PNGRIS drainage class
1	Well
2	Imperfect
3	Poor - very poor
4	Swamps

Not only does the PNGLES system require a maximum of 16 classes for each climatic, soil and topographic layers, but it also requires the climatic, topographic and soil characteristics describing a particular area of land be contained in a single table. It is this single table containing the soil, topographic and climatic characteristics of individual parcels of land that PNGLES compares with the climate, topography and soil requirements of the crop being assessed.

In previous versions of PNGRIS, the table attached to the RMU-based map contained one value for each climatic, soil and topographic attribute per RMU. This table could be imported directly into PNGLES. However, the upgraded version of PNGRIS separated each climate, topographic and soil attribute into individual layers so there is now no single table containing individual values per unit of land. This table must therefore be first constructed from the upgraded PNGRIS layers, and this is done by intersecting each reclassified PNGRIS layer.

A worked example of using PNGLES and PNGRIS to produce a crop suitability map is presented below. This step by step guide is designed for MapInfo users. However, the same basic procedure of intersecting the PNGRIS layers, importing the intersected table into PNGLES, running a crop evaluation, and then joining the resultant crop suitability table to the intersected PNGRIS layers can be used to produce a crop suitability map in ArcGIS.

8.3 Step by step guide to creating a crop suitability map

8.3.1 Step 1: Reclassifying PNGRIS layers to PNGLES classes

Before a PNGLES based crop suitability map can be created, each upgraded PNGRIS layer must be reclassified according to the PNGLES classification system outlined in section 8.2. Reclassifying PNGRIS layers in MapInfo is done by joining a remap table to the PNGRIS layer. A remap table is a table containing one column with a list of each PNGRIS class contained in the upgraded map layer and a column listing the corresponding PNGLES classes. The steps involved in reclassifying the PNGRIS layers into PNGLES categories using the elevation layer as an example are outlined as follows:

8.3.1.1 Create a remap table

A remap table is made by creating a table containing the PNGRIS classes and corresponding PNGLES classes in a spreadsheet package such as Microsoft EXCEL and saving it as a delimited text (.txt) file, as shown in Table 47.

Table 47: Table used to reclassify the upgraded PNGRIS Elevation layer into the 16 classes required to produce crop suitability maps in PNGLES

Code	Elevation/Altitude class (metres)	PNGLES class
1	0 – 100	1
2	100 – 200	1
3	200 – 300	2
4	300 – 400	3
5	400 – 500	4
6	500 – 600	5
7	600 – 700	6
8	700 – 800	6
9	800 – 900	7
10	900 – 1000	7
11	1000 – 1100	8
12	1100 – 1200	8
13	1200 – 1300	9
14	1300 – 1400	9
15	1400 – 1500	10
16	1500 – 1600	10
17	1600 – 1700	11
18	1700 – 1800	11
19	1800 – 1900	12
20	1900 – 2000	12
21	2000 – 2100	13
22	2100 – 2200	13
23	2200 – 2300	14
24	2300 – 2400	15
25	2400 – 2500	15
26	2500 – 2600	15
27	2600 – 2700	15
28	2700 – 2800	15
29	2800 – 2900	15
30	2900 – 3000	16
31	3000 – 3100	16
32	3100 – 3200	16
33	3200 – 3300	16
34	3300 – 3400	16
35	3400 – 3500	16
36	3500 – 3600	16
37	3600 – 3700	16
38	3700 – 3800	16

39	3800	–	3900	16
40	3900	–	4000	16
41	4000	–	4100	16
42	4100	–	4200	16
43	4200	–	4300	16
44	4300	–	4400	16

8.3.1.2 Joining remap table to PNGRIS layers

The next step is to join the remap table to the PNGRIS elevation layer. This is done by adding a column to the MapInfo table which will contain the PNGLES class, in the 'Table – maintenance' menu in MapInfo as shown in Figure 76.

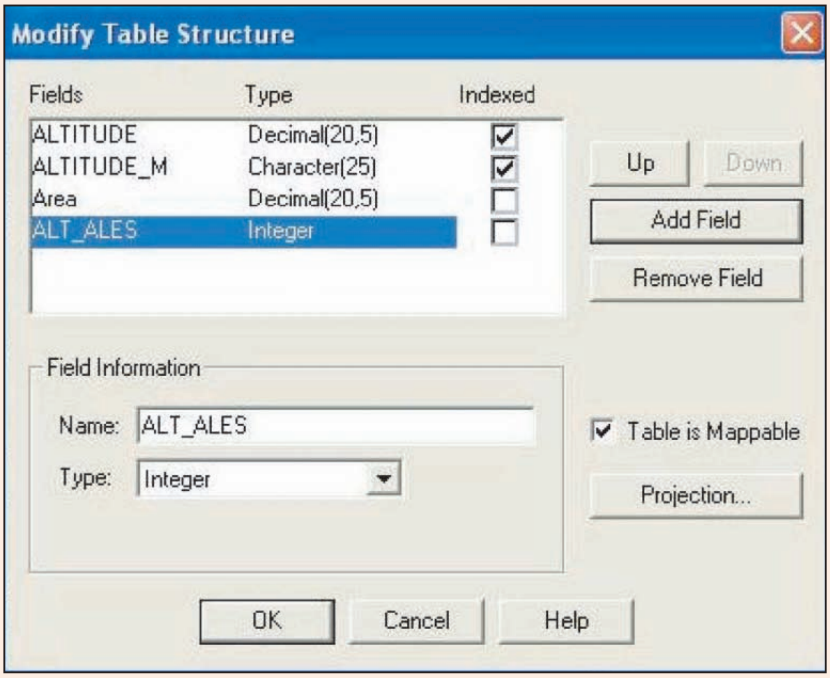

Figure 76: Adding a column to the PNGRIS elevation (altitude) layer to contain the reclassified PNGLES elevation classes. In this example the new column is called 'ALT_ALES'.

The PNGLES values from the remap table are then added to the new column using the ‘Table – Update column’ menu. The remap table containing the PNGLES values is firstly joined to the PNGRIS layer, and then the PNGLES values are added to the new column, as shown in Figure 77.

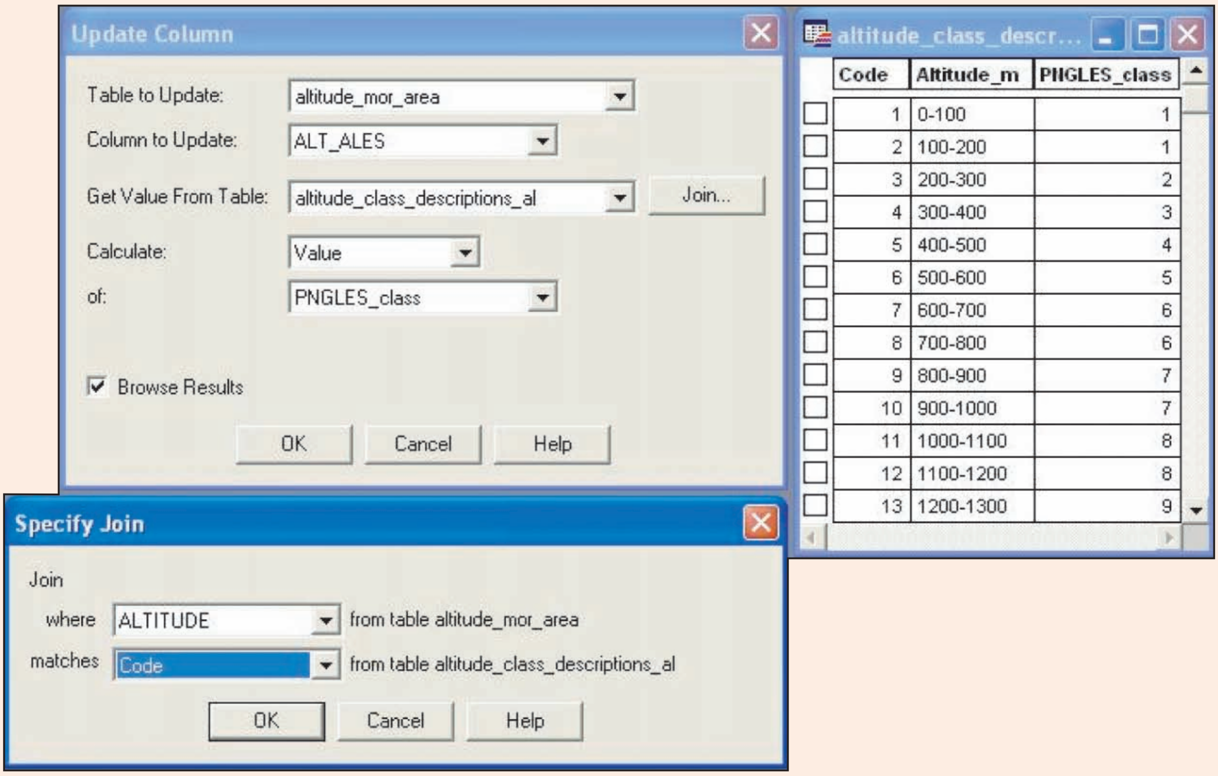

Figure 77: Updating the newly added ALT_ALES column to contain the reclassified PNGLES elevation (altitude) classes.

The result is an elevation layer containing the simplified PNGLES elevation (altitude) classes required by the PNGLES crop suitability program. The same process is employed to reclassify each of the climatic, soil and topographic layers required by PNGLES.

8.3.2 Step 2: Intersecting reclassified PNGRIS layers

Once all PNGRIS layers have been reclassified to be compatible with the PNGLES program, each reclassified layer can now be intersected together to produce a single table containing all the climatic, topographic and soil attributes required to run a PNGLES evaluation. Because the PNGRIS layers are each highly detailed, the land units produced by intersecting each climatic, soil and topographic layers together result in a very large file. It is therefore recommended that each reclassified PNGLES layer be clipped to the boundaries of the area being assessed before the layers are intersected, as shown in Figure 78.

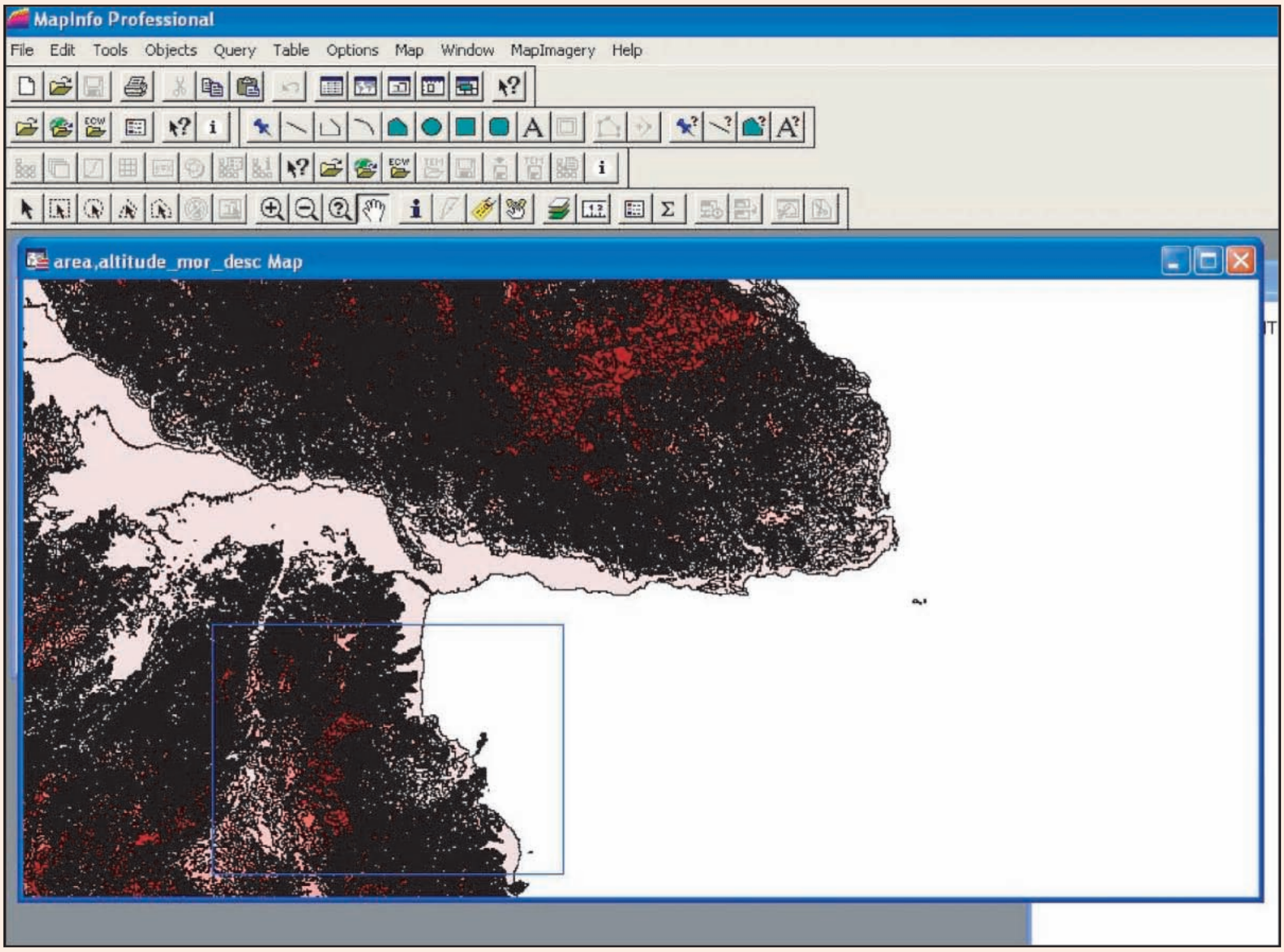

Figure 78: Clipping the elevation layer in Morobe province.

The reclassified PNGLES layers can now be combined into one layer using the 'split' command for each layer being intersected in MapInfo. This process is illustrated in Figure 79.

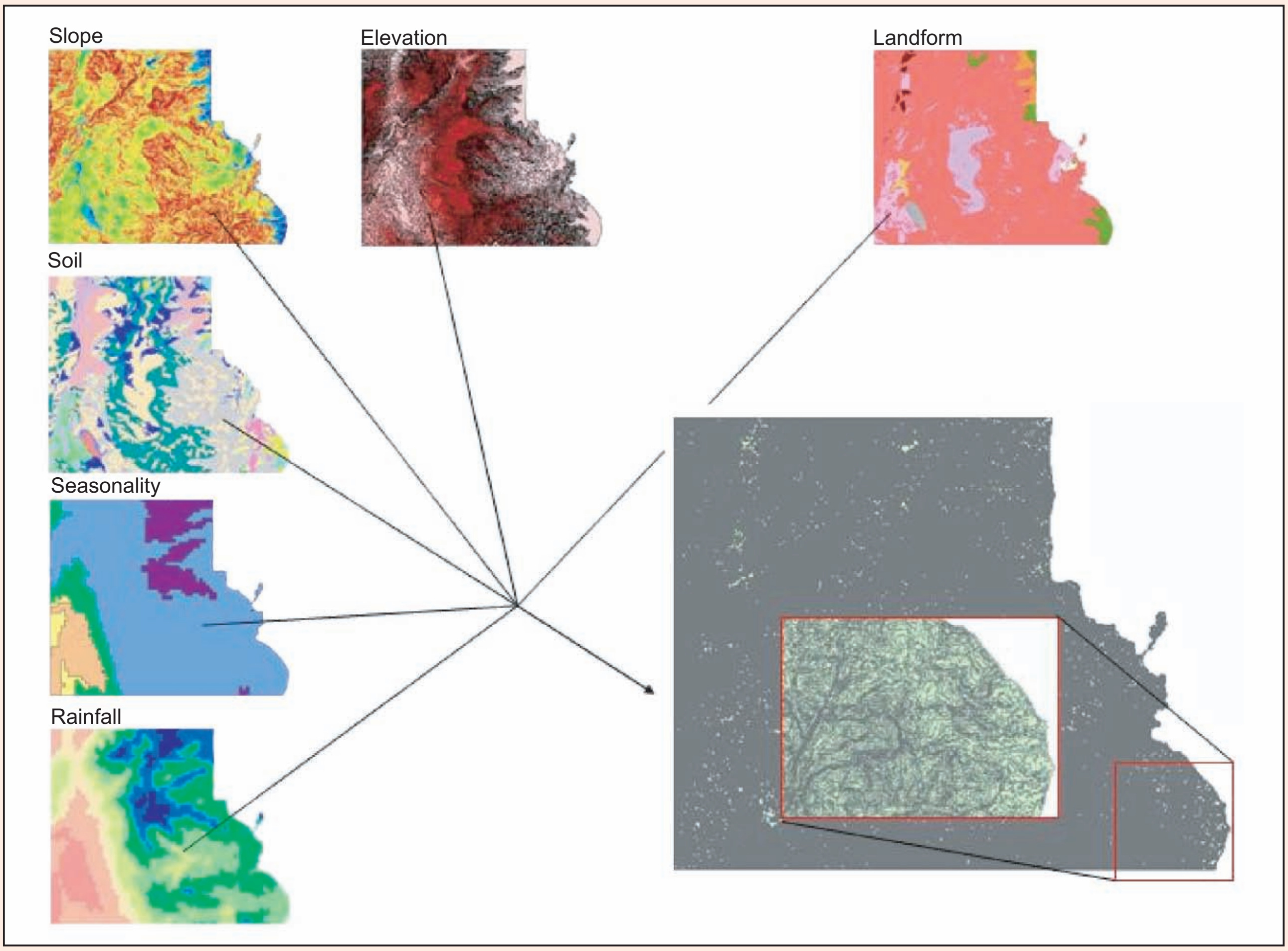

Figure 79: Intersecting each climatic, topographic and soil layer required by PNGLES. The result is one map layer containing a single table with a value for each individual PNGLES attribute.

The values for each layer are added to the resultant intersected layer by adding a column for each attribute and updating it with the relevant values according to the process outlined in section 8.3.1.2.

PNGLES requires that each individual polygon in the intersected layer has its own unique identifier, which is achieved by adding a numbered column to the intersected layer. A numbered column can be created by adding a column called 'ID' in MapInfo and then updating the ID column with a row number using the command 'Int(RowID), as shown in Figure 80.

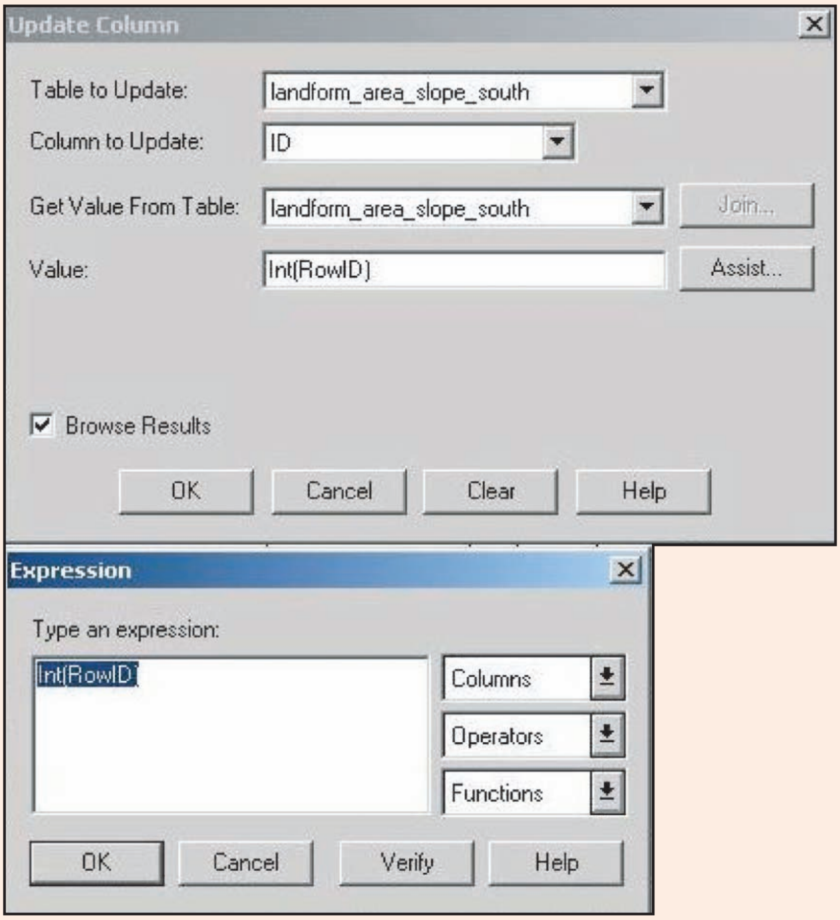

Figure 80: Adding a numbered ID column in MapInfo.

Once all values for all layers have been added to the table, the table can be exported from MapInfo into dBase format, ready to be imported into PNGLES.

8.3.3 Step 3: Entering reclassified PNGRIS land units into PNGLES

PNGLES is accessed by running the ALES program. Full instructions for setting up ALES and importing the PNGLES settings can be found in the ALES instruction manual (Rossiter & Wambeke, 1997). ALES is launched on Microsoft Windows systems by opening the command prompt, navigating to the directory where ALES is stored (c:/dtm is the default directory) using the 'cd' and 'cd ..' commands, and typing 'ales' at the prompt. Once ALES has been launched, the PNGLES dataset should be imported if it is not already contained in ALES. The PNGLES dataset can be opened in ALES by navigating to the 'Build Models and Evaluate' section and using the restore option to open the PNGLES.ALS file into ALES.

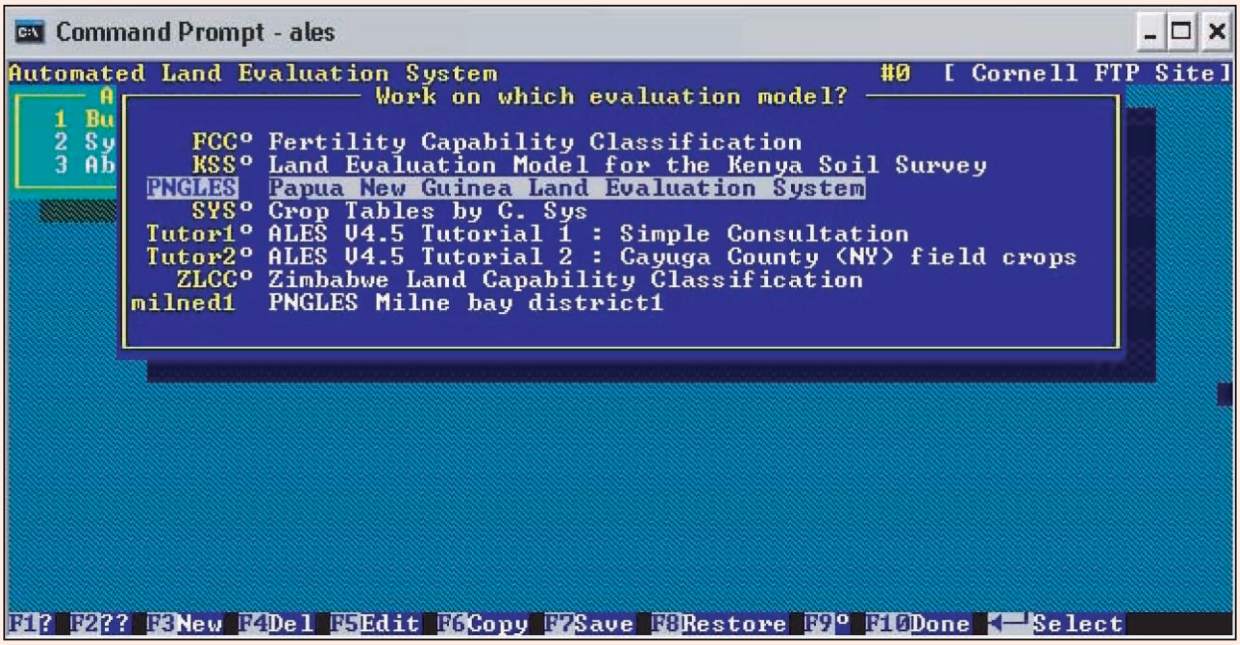

Figure 81: Opening PNGLES dataset inside the ALES program.

Part of PNGLES includes a template for importing the intersected PNGRIS table produced in section 8.3.2. This template requires the user to tell ALES in which directory the intersected table is located.

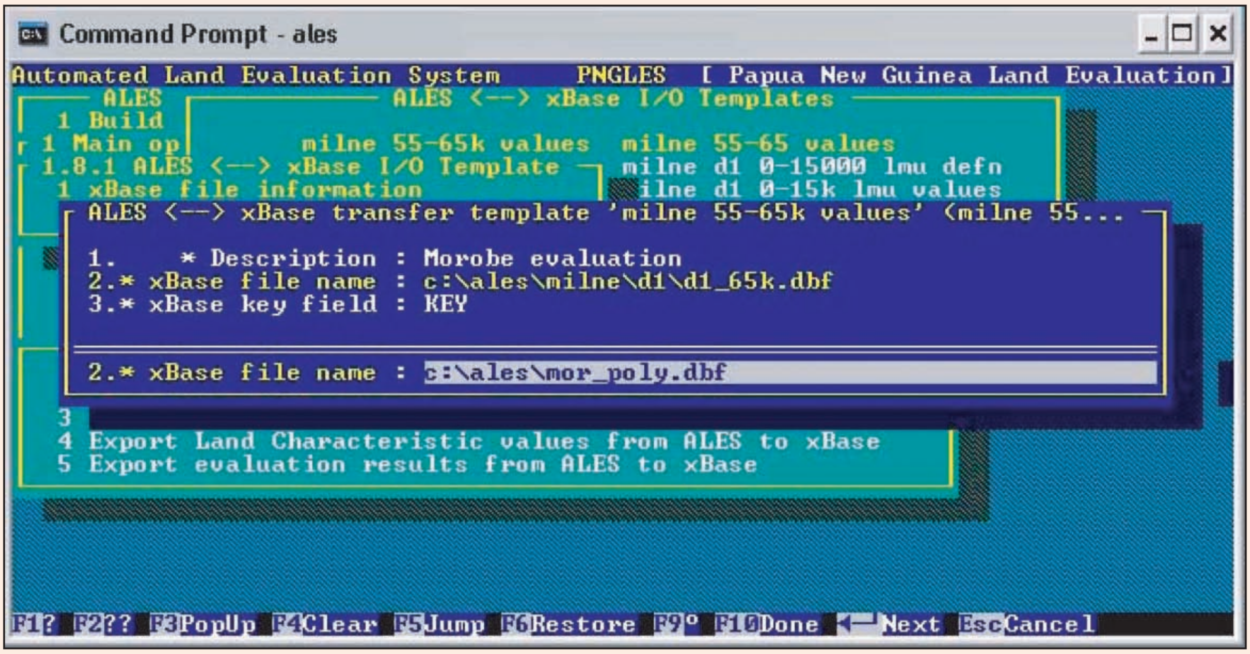

***Figure 82:** The file name of the table containing the climatic, topographic, and soil characteristics of the land being evaluated must be entered into PNGLES. In this example, the file is called 'mor_poly.dbf'. This section of ALES is located by navigating to the 'ALES ➡ xBASE' section of ALES.*

The user must also tell ALES which column in the intersected dBase table corresponds to which climatic, topographic or soil attribute housed in the PNGLES system, as shown in Figure 83.

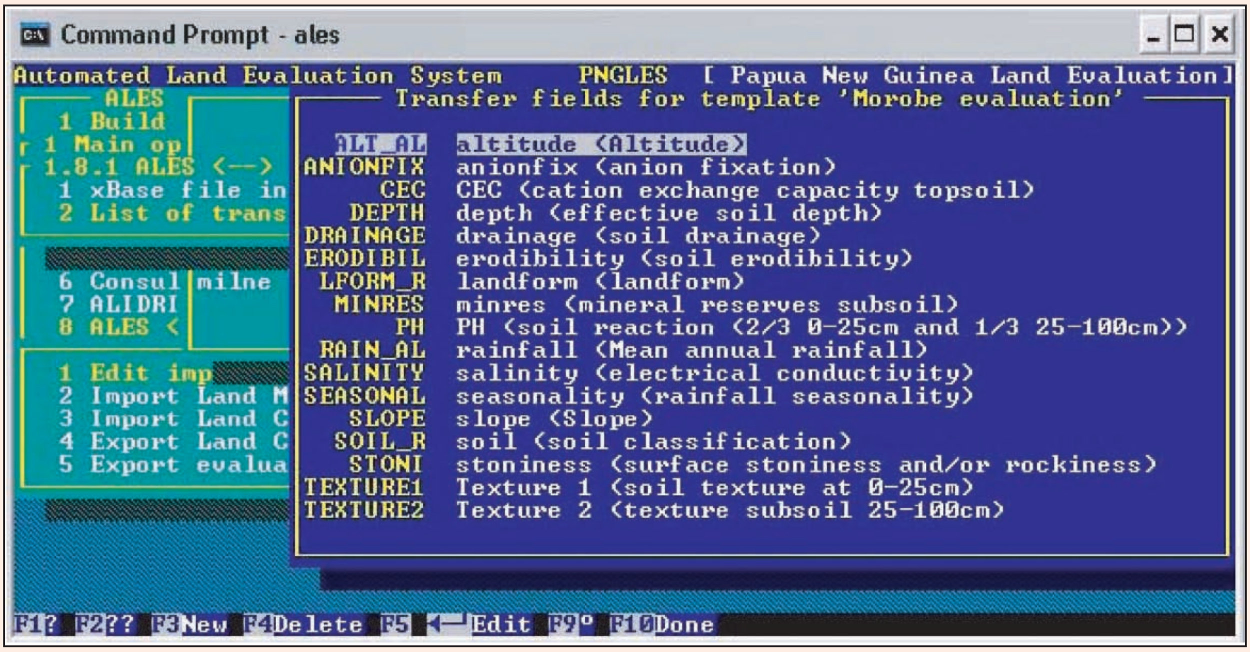

***Figure 83:** Assigning columns contained in the intersected PNGRIS table, shown in the left hand column in yellow, to the corresponding attribute contained in the PNGLES crop requirement database, shown in the right hand column in white.*

The ID number, or definition, referring to each polygon (land mapping unit) in the intersected table is imported first. This is shown in Figure 84.

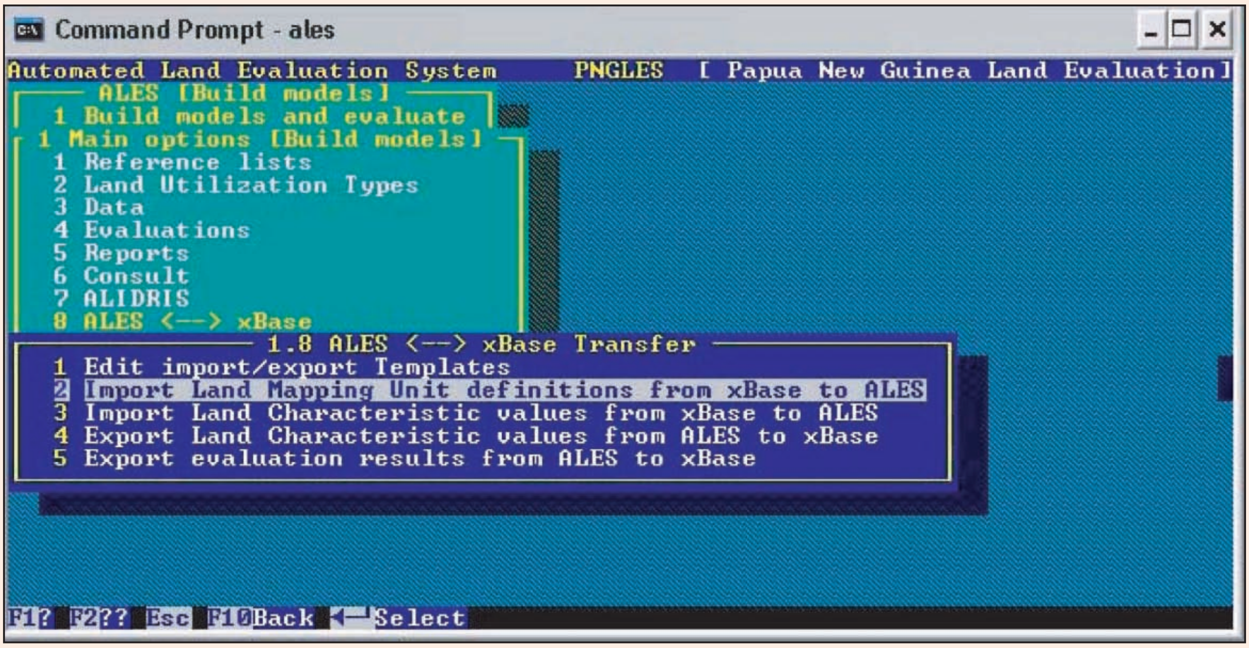

Figure 84: Importing the definitions for each polygon contained in the intersected PNGRIS table.

The climatic, soil and topographic values for each polygon (land mapping unit) represented in the intersected reclassified PNGRIS table is then imported, as shown in Figure 85.

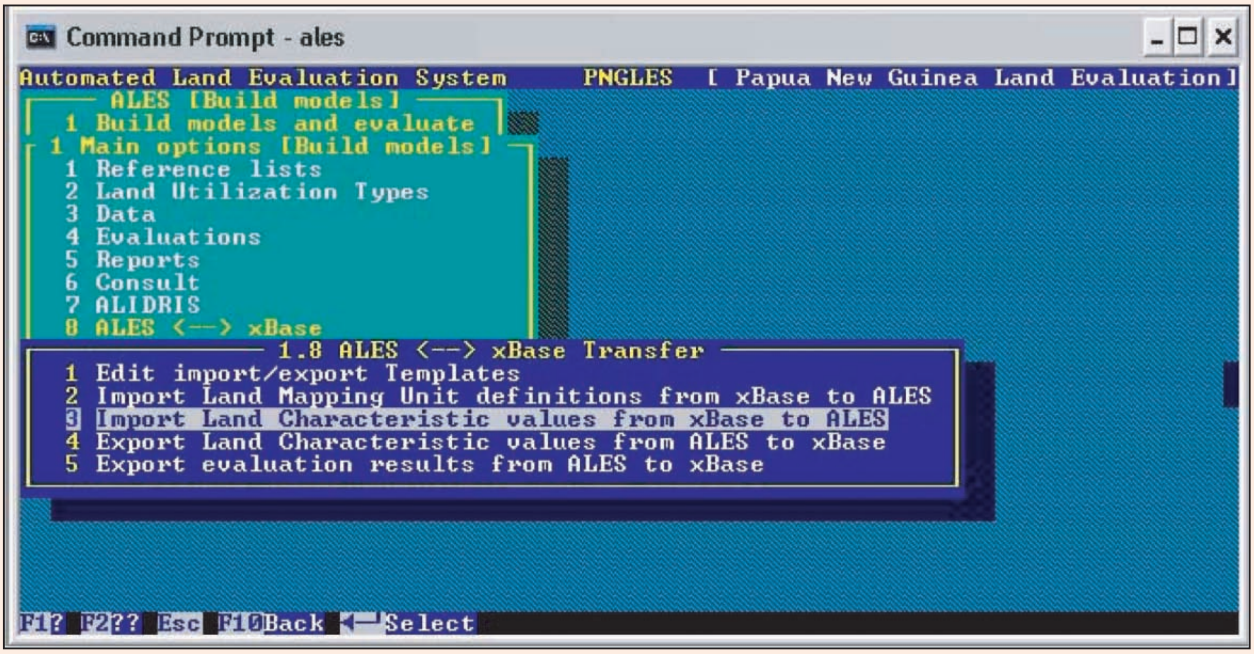

Figure 85: Importing the climatic, topographic and soil values, called 'Land characteristics', contained in the intersected PNGRIS table.

If the table is too big to be imported, save it as two separate files and run the suitability analysis on each one separately.

Once the intersected table containing the climatic, soil and topographic attributes of the land area being assessed has been imported into ALES, it is now ready to be compared to the climatic, soil and topographic requirements of the particular crop being assessed for suitability. A suitability assessment or ‘evaluation’ is produced using the ‘Evaluation’ component of ALES, as shown in Figure 86.

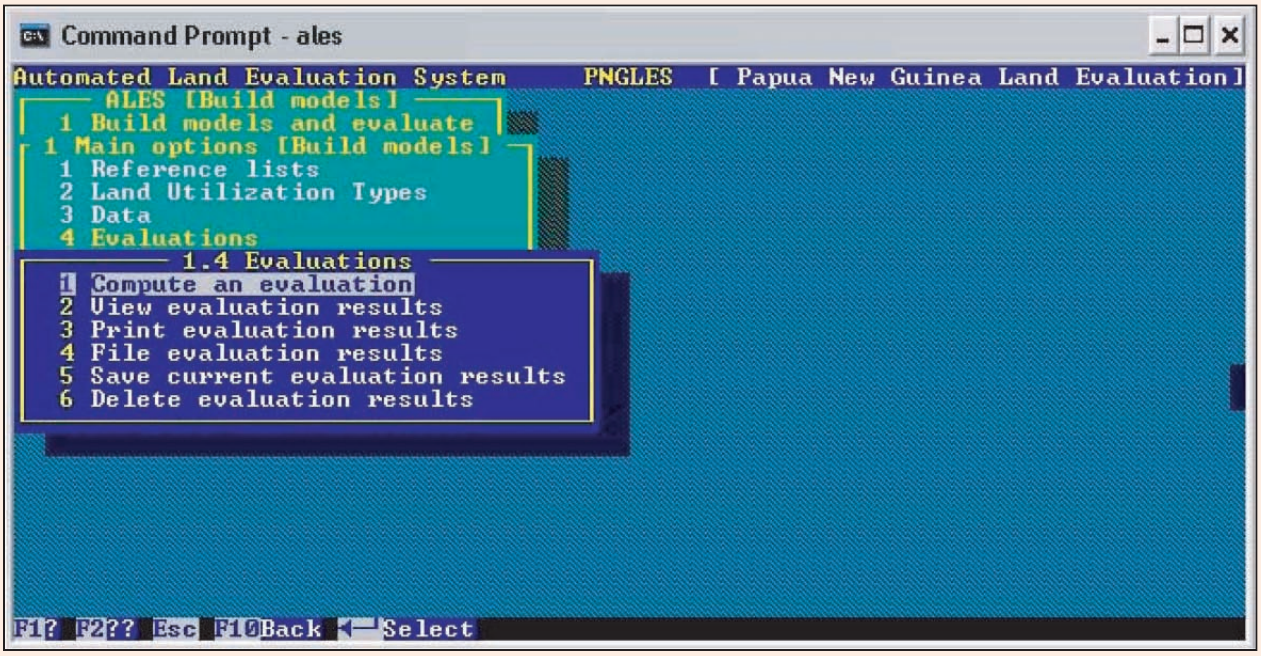

Figure 86: A crop suitability assessment is run using the ‘Evaluation’ component of ALES.

Inside the ‘Evaluation’ component of PNGLES, the list of 18 crops contained in PNGLES can be found. Choosing a crop from the list and running the ‘evaluation’ component will automatically compute a suitability assessment on the table containing the intersected PNGRIS layers.

8.3.3.1 Saving the crop suitability table

The result of this ‘evaluation’ is a table containing a suitability rating for each polygon in the intersected PNGRIS table. The suitability table is saved using the ‘File evaluation results’ option, as shown in Figure 86. The output table is in tab delimited text file format. Once the crop evaluation has been saved, another crop can be chosen from the list and another crop suitability table will be produced.

8.3.4 Step 4: Joining a suitability table to the intersected PNGRIS layer

The next step is to import the crop suitability table into MapInfo and join it to the intersected PNGRIS layer.

To view the crop suitability map, import the suitability table or tables created in the ALES 'Evaluation' model into MapInfo, and join it to the intersected reclassified PNGRIS layer. The join is made based on the 'ID' number added to the intersected PNGRIS layer, shown in Figure 80.

The result is a detailed crop suitability map shown in Figure 74 at the beginning of this section. Two examples of crop suitability maps for coffee in Simbu province and oil palm in Milne Bay province are also presented in Figures 87 and 88.

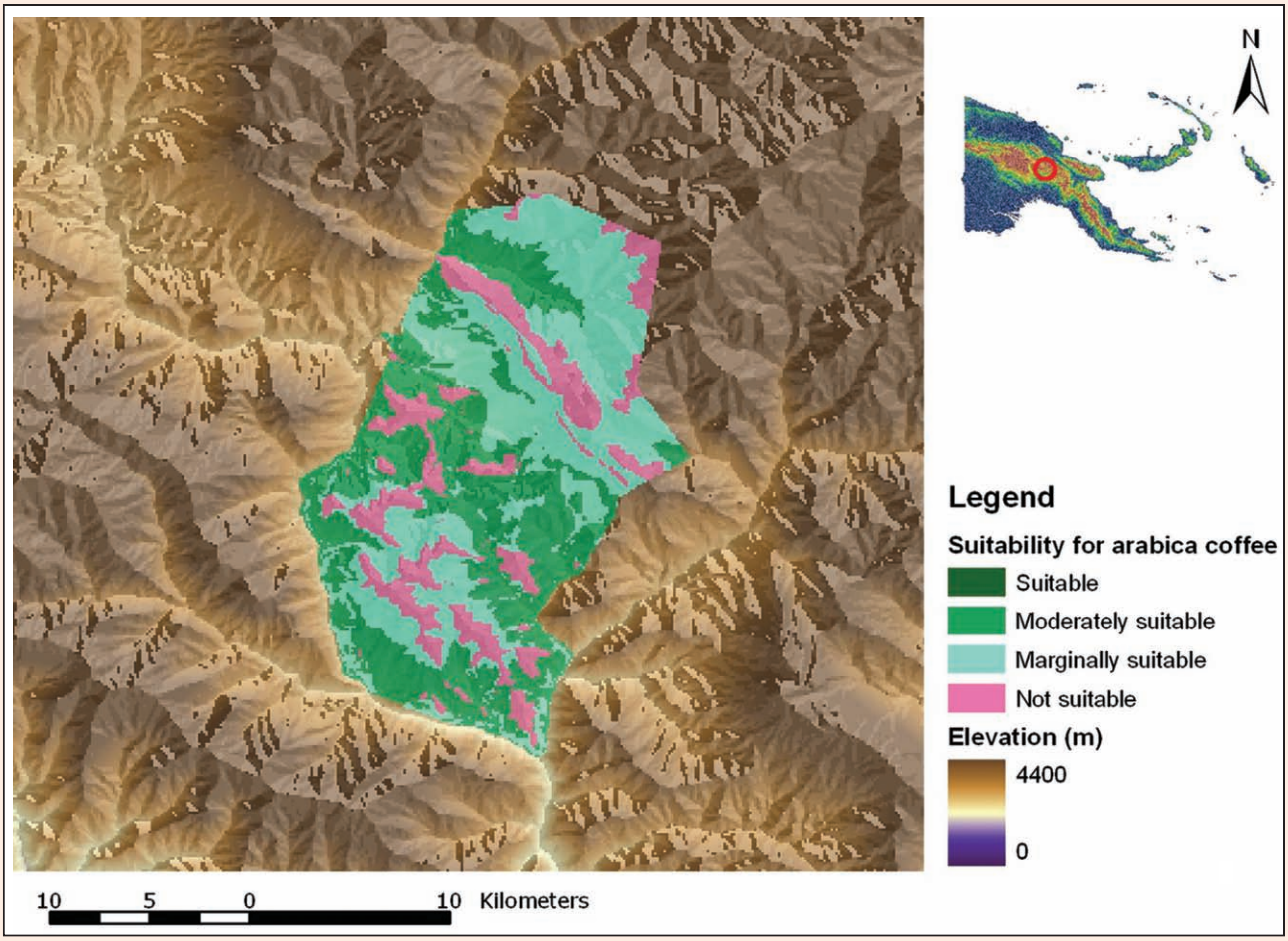

Figure 87: Suitability for growing Arabica coffee (low capital input) in the Sina Sina district in Simbu province. The suitability map was made using the upgraded PNGRIS datasets and the PNGLES program. The tops of the hills where the soil is shallow and/or rocky is rated by PNGLES as unsuitable, whereas the less steep valleys and lower slopes are rated as more suitable for growing coffee (low capital input).

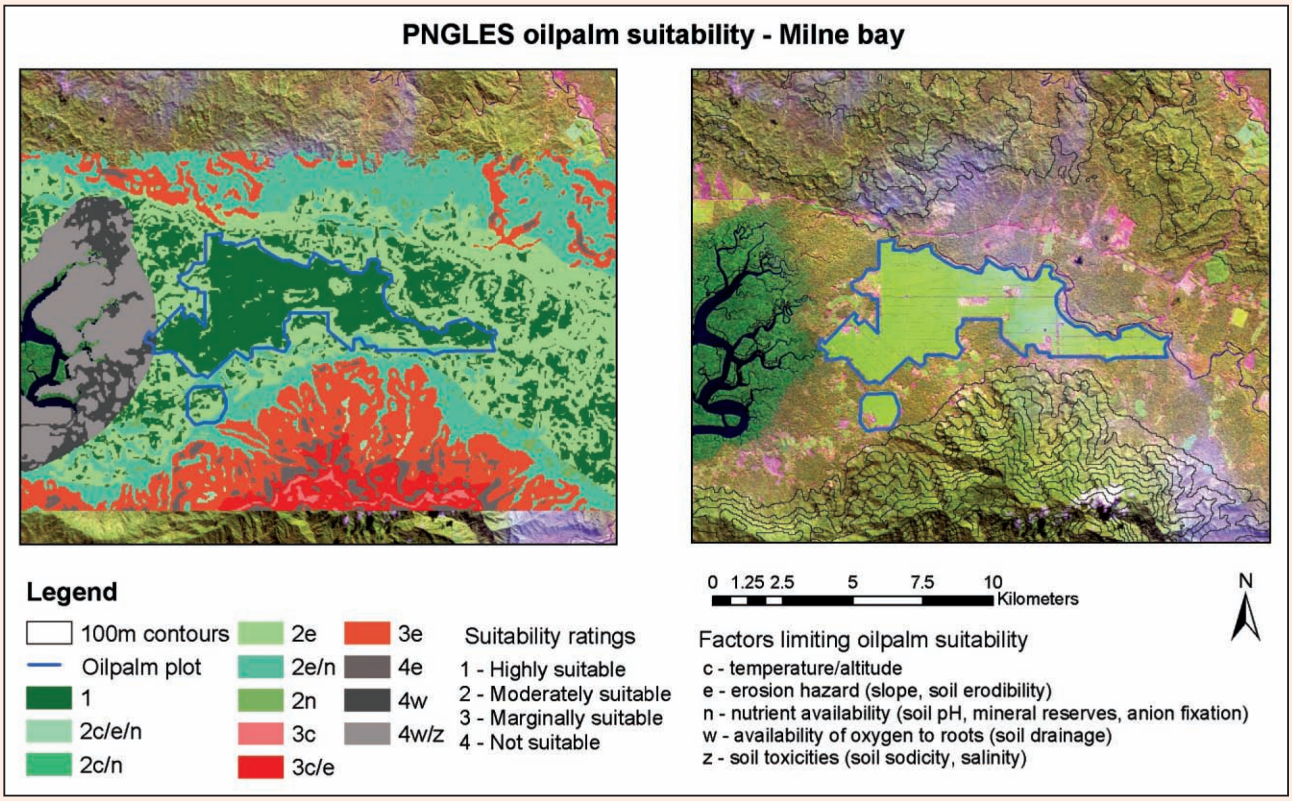

Figure 88: Suitability for growing oil palm in Milne Bay province. The background is a SPOT5 satellite image of the area showing an oil palm plantation. The oil palm plantation can be seen in bright green in the right hand image. The suitability map for oil palm is shown in the left hand image. Areas rated by PNGLES as suitability for growing oil palm correspond well to the location of the oil palm plantation. The mangrove swamp in the centre left of the right hand image is rated by PNGLES as unsuitable, and the steeper slopes to the south of the oil palm plantation are rated as marginally suitable.

8.4 Limitations

Crop suitability mapping using the PNGLES system carries with it a number of limitations.

Firstly, all of the limitations of the climatic, soil and topographic datasets discussed in sections 2 - 5 also apply to the crop suitability maps generated from them.

Secondly, the assessments of suitability are only as good as the series of rules inside PNGLES (see Venema & Daink, 1992) devised to assign suitability ratings in PNGLES. All of these decision rules can be changed inside PNGLES as and when better crop information becomes available. The suitability assessments produced using PNGLES should be viewed as a guide only and interpreted in relation to the individual datasets used to produce them.

It is also important to note that there are other methods of assessing crop suitability that do not use the ALES system, and users may wish to interact directly with the upgraded PNGRIS layers in MapInfo, or another GIS, to derive their own assessments of suitability.

It is also important to understand that PNGLES assesses the land for physical suitability for growing particular crops, and at this stage does not assess economic suitability. That is, the landscape may be suitable for growing a particular crop, but the market price for the crop is less than the cost of growing it or transporting it to market. The ALES program has the capacity to produce an economic assessment, but market prices and costs of production need to be entered. The instructions for doing this can be found in the ALES documentation (Rossiter & Wambeke, 1997).

8.5 References

Rossiter, D., Wambeke, A.R. (1997). Automated Land Evaluation System ALES Version 4.65 User's Manual. Department of Soil, Crop & Atmospheric Sciences. Cornell University. New York. http://www.css.cornell.edu/landeval/ales/ales.htm

Venema, J.H. & Daink, F. (1992). Land Evaluation and Landuse Planning for Agricultural Expansion and Diversification: Papua New Guinea Land Evaluation Systems (PNGLES). Department of Agriculture and Livestock Land Utilisation Section, Food and Agriculture Organization of the United Nations. Port Moresby.

Appendix 2

9 Dataset attributes and codes

9.1 Topographic map layers

Table 48: Elevation code and description

Code	Elevation/Altitude class (metres)
1	0 – 100
2	100 – 200
3	200 – 300
4	300 – 400
5	400 – 500
6	500 – 600
7	600 – 700
8	700 – 800
9	800 – 900
10	900 – 1000
11	1000 – 1100
12	1100 – 1200
13	1200 – 1300
14	1300 – 1400
15	1400 – 1500
16	1500 – 1600
17	1600 – 1700
18	1700 – 1800
19	1800 – 1900
20	1900 – 2000
21	2000 – 2100
22	2100 – 2200
23	2200 – 2300
24	2300 – 2400
25	2400 – 2500
26	2500 – 2600
27	2600 – 2700
28	2700 – 2800
29	2800 – 2900
30	2900 – 3000
31	3000 – 3100
32	3100 – 3200
33	3200 – 3300
34	3300 – 3400
35	3400 – 3500
36	3500 – 3600
37	3600 – 3700
38	3700 – 3800
39	3800 – 3900
40	3900 – 4000
41	4000 – 4100
42	4100 – 4200
43	4200 – 4300
44	4300 – 4400

Table 49: Topographic Position code and description

Code	Topographic position	Description
1	Valley bottom flat	Local low area in the landscape, flat (slope = 0 degrees)
2	Valley bottom undulating	Local low area in the landscape, undulating (slope >0 and <2 degrees)
3	Lower slope 2	Local low area in the landscape, slopes >2 degrees
4	Lower slope 1	Lower slope
5	Mid slope	Mid slope
6	Upper slope/ridge top	Local highest area in the landscape

Table 50: Slope code and description

Code	Slope (degrees)
1	0
2	0 – 2
3	2 – 5
4	5 – 10
5	10 – 15
6	15 – 20
7	20 – 25
8	25 – 30
9	30 – 35
10	>35

Table 51: Landform code and description

Code	Aspect (direction)	Aspect (degrees from north)
1	North	337.5 – 360, 0 – 22.5
2	North East	22.5 – 67.5
3	East	67.5 – 112.5
4	South East	112.5 – 157.5
5	South	157.5 – 202.5
6	South West	202.5 – 247.5
7	West	247.5 – 292.5
8	North West	292.5 – 337.5
9	Flat	Flat

Table 52: Landform code and description

Code	Depositional landforms
	Littoral
	Recent
1	Mangrove swamps
2	Estuarine plains and deltas
3	Beach ridge complexes and beach plains
4	Undifferentiated coastal plain
	Relict
5	Relict beach ridges and plains
6	Raised coral reefs and associated back reef plains
	Fluvial
	Relict plains
9	Intricately dissected relict alluvial plains
10	Gently undulating relict alluvial plains with broad swampy drainage depressions
	Recent plains
12	Narrow alluvial floodplains and flanking terraces
13	Composite alluvial plains
15	Meander floodplains
18	Composite levee plains
21	Back plains
22	Back swamps
23	Blocked or drowned valley swamps and lakes and their associated swampy floodplains
24	Undifferentiated swamps
25	Braided floodplains or bar plains
	Recent fans
26	Composite bar plain and alluvial fan complex
28	Little dissected recent alluvial fans
	Relict fans
30	Little dissected or undissected relict alluvial, colluvial and mudflow fans
31	Dissected relict alluvial, colluvial and mudflow fans
	Erosional landforms
	Landforms of fluvial erosion and mass movement
	Structural surfaces
43	Structural plateau
45	Finely dissected sloping erosional surface with structural control
	Mountains and hills
50	Hilly terrain with weak or no structural control
51	Mountains or hills with weak or no structural control
52	Mountains and hills associated with relict surfaces with weak or no structural control
53	Homoclinal ridges and cuestas
54	Strike ridges and hogback ridges

	Erosional landforms
	Landforms of karst erosion
	Plains
11	Karst plains
	Plateaux
42	Limestone plateaux with narrow karst corridors
	Mountains and hills
55	Polygonal karst
	Volcanic landforms
	Fans and footslopes
32	Little dissected volcanic footslopes and volcano-alluvial fans
33	Dissected volcanic footslopes and volcano-alluvial fans
34	Deeply dissected older volcanic footslopes and fans
35	Volcano-alluvial plains
	Plateaux
41	Dissected volcanic plateau
	Mountains and hills
56	Volcanic cones and domes
	Water bodies
60	Lake

9.2 Climatic map layers

Table 53: Mean annual rainfall code and description

Code	Mean annual rainfall (mm)		
1	1000	–	1100
2	1100	–	1200
3	1200	–	1300
4	1300	–	1400
5	1400	–	1500
6	1500	–	1600
7	1600	–	1700
8	1700	–	1800
9	1800	–	1900
10	1900	–	2000
11	2000	–	2100
12	2100	–	2200
13	2200	–	2300
14	2300	–	2400
15	2400	–	2500
16	2500	–	2600
17	2600	–	2700
18	2700	–	2800
19	2800	–	2900
20	2900	–	3000
21	3000	–	3100
22	3100	–	3200
23	3200	–	3300
24	3300	–	3400
25	3400	–	3500
26	3500	–	3600
27	3600	–	3700
28	3700	–	3800
29	3800	–	3900
30	3900	–	4000
31	4000	–	4100
32	4100	–	4200
33	4200	–	4300
34	4300	–	4400
35	4400	–	4500
36	4500	–	4600
37	4600	–	4700
38	4700	–	4800

Code	Mean annual rainfall (mm)		
39	4800	–	4900
40	4900	–	5000
41	5000	–	5100
42	5100	–	5200
43	5200	–	5300
44	5300	–	5400
45	5400	–	5500
46	5500	–	5600
47	5600	–	5700
48	5700	–	5800
49	5800	–	5900
50	5900	–	6000
51	6000	–	6100
52	6100	–	6200
53	6200	–	6300
54	6300	–	6400
55	6400	–	6500
56	6500	–	6600
57	6600	–	6700
58	6700	–	6800
59	6800	–	6900
60	6900	–	7000
61	7000	–	7100
62	7100	–	7200
63	7200	–	7300
64	7300	–	7400
65	7400	–	7500
66	7500	–	7600
67	7600	–	7700
68	7700	–	7800
69	7800	–	7900
70	7900	–	8000
71	8000	–	8100
72	8100	–	8200
73	8200	–	8300
74	8300	–	8400
75	8400	–	8500
76	8500	–	8600

Table 54: Rainfall seasonality code and description

Code	Rainfall per month	Description
1	<100mm to >200mm; >200mm dominant	Large rainfall range, heavy to light monthly rainfall, heavy dominant
2	<100mm to >200mm; <100mm dominant	Large rainfall range, heavy to light monthly rainfall, light dominant
3	100 – 200mm to >200mm	Moderate rainfall range, heavy to intermediate monthly rainfall
4	<100mm to 100 – 200mm	Moderate rainfall range, intermediate to light monthly rainfall
5	All months >200mm	Continuously heavy monthly rainfall
6	All months 100 – 200mm	Continuously intermediate monthly rainfall

Table 55: Mean annual minimum temperature code and description

Code	Mean annual minimum temperature (°C)
1	0.5 – 1.0
2	1.0 – 2.0
3	2.0 – 3.0
4	3.0 – 4.0
5	4.0 – 5.0
6	5.0 – 6.0
7	6.0 – 7.0
8	7.0 – 8.0
9	8.0 – 9.0
10	9.0 – 10.0
11	10.0 – 11.0
12	11.0 – 12.0
13	12.0 – 13.0
14	13.0 – 14.0
15	14.0 – 15.0
16	15.0 – 16.0
17	16.0 – 17.0
18	17.0 – 18.0
19	18.0 – 19.0
20	19.0 – 20.0
21	20.0 – 21.0
22	21.0 – 22.0
23	22.0 – 23.0
24	23.0 – 24.0
25	24.0 – 25.0

Table 56: Mean annual maximum temperature code and description

Code	Mean annual maximum temperature (°C)
1	3.5 – 4.0
2	4.0 – 5.0
3	5.0 – 6.0
4	6.0 – 7.0
5	7.0 – 8.0
6	8.0 – 9.0
7	9.0 – 10.0
8	10.0 – 11.0
9	11.0 – 12.0
10	12.0 – 13.0
11	13.0 – 14.0
12	14.0 – 15.0
13	15.0 – 16.0
14	16.0 – 17.0
15	17.0 – 18.0
16	18.0 – 19.0
17	19.0 – 20.0
18	20.0 – 21.0
19	21.0 – 22.0
20	22.0 – 23.0
21	23.0 – 24.0
22	24.0 – 25.0
23	25.0 – 26.0
24	26.0 – 27.0
25	27.0 – 28.0
26	28.0 – 29.0
27	29.0 – 30.0
28	30.0 – 31.0
29	31.0 – 32.0
30	32.0 – 33.0
31	33.0 – 34.0

Table 57: Mean annual solar radiation code and description

Code	Mean annual radiation (MJ/m^2)		
1	15.50	–	17.75
2	15.75	–	16.00
3	16.00	–	16.25
4	16.25	–	16.50
5	16.50	–	16.75
6	16.75	–	17.00
7	17.00	–	17.25
8	17.25	–	17.50
9	17.50	–	17.75
10	17.75	–	18.00
11	18.00	–	18.25
12	18.25	–	18.50
13	18.50	–	18.75
14	18.75	–	19.00
15	19.00	–	19.25
16	19.25	–	19.50
17	19.50	–	19.75
18	19.75	–	20.00
19	20.00	–	20.25
20	20.25	–	20.50

9.3 Soil map layer

Table 58: Soil code and description

Order	Suborder	Great group	Code	Distribution	Major previously named soil group
Entisols	Aquents	Cryaquents	110	Very local	Skeletal soils, Peat soils
		Sulfaquents	111	Common	Saline Peats and Muds, Mangrove soils
		Hydraquents	112	Very common	Young Alluvial soils, very poorly drained Alluvial soils
		Fluvaquents	113	Very common	Alluvial soils, Young Alluvial soils, Recent Alluvial soils
		Tropaquents	114	Very common	As for Fluvaquents
		Psammaquents	115	Common	Recent Alluvial soils
	Psamments	Tropopsamments	121	Common	Coarse textured Beach soils
		Ustipsamments	122	Very local	Coarse textured Beach soils
	Fluvents	Tropofluvents	131	Common	Young Alluvial soils, Recent Alluvial soils, coarse textured Beach soils
		Ustifluvents	132	Local	As for Tropofluvents
	Orthents	Troporthents	141	Very common	Lithosols, Skeletal soils, Slope soils
		Cryorthents	142	Very local	As for Troporthents
		Ustorthents	143	Very local	Colluvial soils
Histosols	Folists	Cryofolists	211	Very local	Alpine Peat and Humus soils
		Tropofolists	212	Common	Peat soils, Alpine Peat and Humus soils
	Hemists	Sulfihemists	220	Very local	Saline Peats and Muds
		Cryohemists	221	Very local	Alpine Peats and Humus soils
		Tropohemists	222	Common	Peat soils, Organic soils, Bog soils
	Fibrists	Cryofibrists	231	Very local	Alpine Peat and Humus soils
		Tropofibrists	232	Common	Peat soils, Organic soils, Bog soils
	Saprists	Troposaprists	241	Common	Peat soils, Organic soils, Bog soils
Inceptisols	Aquepts	Halaquepts	311	Very local	Low Humic Gley soils, Alluvial soils
		Cryaquepts	312	Very local	Skeletal soils, Peat soils
		Andaquepts	313	Local	Humic Olive Ash soils, Unweathered Sandy Volcanic soils with black topsoils
		Tropaquepts	314	Common	Gleyed Plastic Heavy clay soils, Dark soils of Heavy Texture, Gleyed Pelosols
		Plinthaquepts	315	Very local	Gleyed Plastic Heavy clay soils
	Andepts	Cryandepts	320	Very local	Humic Brown Clay soils (on volcanic ash)
		Hydrandepts	321	Very common	Humic Brown Clay soils (on volcanic ash), Latosolic Andosols
		Eutrandepts	322	Very common	Moderately weathered Brown Ash soils

Order	Suborder	Great group	Code	Distribution	Major previously named soil group
Inceptisols	Aquepts	Dystrandepts	323	Common	Moderately to little weathered Brown ash soils
		Vitrandepts	324	Very common	Unweathered Sandy Volcanic soils with black topsoil
		Durandepts	325	Very local	Brown Loams with an ash pan
	Tropepts	Humitropepts	331	Very common	Humic Brown Clay soils
		Ustropepts	332	Local	Brown Clay soils
		Eutropepts	333	Very common	Brown Forest soils, Dark Alluvial soils, Shallow Dark Clay soils, Reddish Clay soils
		Dystropepts	334	Very common	Strongly weathered Red and Brown Clay soils, Acid Red to Brown Clay soils, Acid Brown Forest soils, Uniform Red and Yellow Clays, Reddish Clay soils
	Ochrepts	Cryochrepts	341	Very local	Alpine Peat and Humus soils, Skeletal soils
	Umbrepts	Cryumbrepts	351	Very local	Alpine Peat and Humus soils, Skeletal soils
Vertisols	Uderts	Pelluderts	411	Local	Alluvial Black Clay soils, Black sols Earths, Grumusols
	Usterts	Pellusterts	421	Very local	Dark Cracking Clay soils, Grumusols
Mollisols	Aquolls	Argiaquolls	511	Local	Dull Meadow Podzolic soils, Meadow Podzolic soils
		Haplaquolls	512	Common	As for Argiaquolls but also poorly drained old Alluvial soils and Gleyed Pelosols
	Rendolls	N/A	520	Very common	Rendzinas, Limestone soils
	Ustolls	Natrustolls	531	Very local	Shallow Black Earths, Texture Contrast soils
		Calciustolls	532	Very local	Texture contrast soils, Brown clay soils
		Argiustolls	533	Very local	As for Calciustolls
		Haplustolls	534	Very local	Dark Cracking Clay soils, Beach soils
	Udolls	Argiudolls	541	Common	Well drained Old Alluvial soils, Immature Brown soils on sedimentary rocks, Dull Meadow Podzolic soils, Meadow Podzolic soils
		Hapludolls	542	Very common	Young Alluvial soils, well-drained old Alluvial Black Clay soils
Alfisols	Aqualfs	Albaqualfs	610	Very local	Meadow Podzolic soils
		Plinthaqualfs	611	Common	Meadow Podzolic soils, Meadow soils
		Tropaqualfs	612	Common	As for Plinthaqualfs but also Gleyed Plastic Heavy Clay soils and Weathered Gleyed soils
	Ustalfs	Natrustalfs	621	Very local	Textured Contrast soils
		Rhodustalfs	622	Very local	Alkaline Reddish Clay soils
		Haplustalfs	623	Local	Texture Contrast soils, Brown clay soils
	Udalfis	Natrudalfs	631	Very local	Brown Forest soils
		Rhodudalfs	632	Local	Terra Rossas
		Tropudalfs	633	Very common	Dull Meadow Podzolic soils, Brown forest soils, Immature brown soils on sedimentary rocks

Order	Suborder	Great group	Code	Distribution	Major previously named soil group
Ultisols	Aquults	Paleaquults	710	Very local	Podzolized Gley Laterites, Lateritic and Gleyed Latosols
		Plinthaquults	711	Common	Meadow Podzolic soils, Podzolic Lateritic soils, Podzolized Gley Laterites
		Albaquults	712	Local	Meadow Podzolic soils, Lateritic and Gleyed Latosols
		Tropaquults	713	Common	Meadow soils, Meadow Podzolic soils, Gleyed Plastic Heavy Clay soils, Lateritic and Gleyed Latosols
	Humults	Palehumults	720	Local	Humic Brown Clay soils, Latosolic Andosols
		Plinthohumults	721	Local	Lateritic and Gleyed Latosol
		Tropohumults	722	Common	Humic Brown Clay soils, Humic Brown and Red Latosols, Strongly Weathered Red and Brown Clay soils
	Udults	Paleudults	730	Local	Lateritic soils, Podzolic Lateritic soils
		Plinthudults	731	Common	Red and Yellow Earths, Meadow Podzolic soils
		Rhodudults	732	Local	Acid Red to Brown Clay soils
		Tropudults	733	Common	As for Rhodudults but also Dull Meadow Podzolic soils
Oxisols	Humox	Haplohumox	811	Very local	Strongly weathered Red and Brown Clay soils
		Acrohumox	812	Very local	As for Haplohumox
	Orthox	Haplorthox	821	Very local	Acid Red to Brown Clay soils
		Eutrorthox	822	Very local	Granular Dark Red Uniform Heavy Clay soils

9.4 Geology map layers

Table 59: Rock Type code and description

ROCK TYPE	CODE	DESCRIPTION
SEDIMENTARY ROCKS		
Consolidated non-calcareous		
Fine grained sedimentry	11	Mostly shale, siltstone, mudstone, and marl, which are composed of silt and finer grade particle sizes
Coarse grained sedimentary	12	Mostly sandstone, greywacke and conglomerate which are grade particle sizes
Mixed or undifferentiated sedimentary	13	Includes either a mixture of fine to coarse grained sedimentary rocks or the predominant grain size may be unknow
Consolidated calcareous		
Mixed sedimentary and limestone	14	Interbedded layers of limestone and (frequently calcareous) sedimentary rocks
Limestone	15	Consolidated sedimentary rocks high in carbonates but of variable grain size
Semi-consolidated		
Pleistocene sediments	40	Weakly consolidated fluvial or deltaic sediments of Pleistocene (or occasionally Pliocene) age and which generally associated with relict landform types. These sediments are of variable texture, ranging from sandy clay deposits to boulder conglomerate, and generally deeply weathered
Unconsolidated		
Alluvial deposits	41	All detrital material of Recent age deposited by flowing water and/or gravity. They encompass fluviatile, colluvial (scree), lacustrine and alluvial fan deposits composed of sand, gravel, silt, mud, clay, or angular rock fragments
Marine sands	42	Accumulations of sediment, typically sand, deposited by wave action and modified by wind along a coastline
Estuarine deposits	43	Mud, sand, silt, and clay sediments associated with tidal flats, estuarine and mangrove swamps. These sediments are predominantly fine grained and derived from material deposited by the interaction of fluvial and tidal processes and relatively strong wave-induced long shore currents.
METAMORPHIC ROCKS		
Consolidated		
High grade metamorphic	21	Relatively coarse grained metamorphic rocks, such as schists, gneiss and amphibolites
Low grade metamorphic	22	Relatively fine grained metamorphic rocks, such as slates and phyllites
Mixed or undifferentiated metamorphics	23	Either a mixture of low to high grade metamorphic rocks or metamorphic rocks of unknown grade

ROCK TYPE IGNEOUS ROCKS	CODE	DESCRIPTION
Consolidated extrusive		
Mixed sedimentary and volcanics	30	Areas of complex lithology of sedimentary and volcanic igneous rocks or volcanolithic sediments
Basic to intermediate volcanic	31	Largely basalts, dolerites and andesites, which are fine grained volcanic rocks with relatively low silica content
Intermediate to acid volcanic	32	Mostly rhyolites and dacites, which are fine grained volcanic rocks with relatively high silica contents
Mixed or undifferentiated volcanic	33	Volcanic igneous rocks of either unknown or highly variable composition
Mixed volcanic and limestone	34	Areas of complex lithology of volcanic igneous rocks and limestone
Acid to intermediate igneous	35	Coarse grained igneous rocks with relatively high silica content, such as granites and granodiorites with some diorites and trachytes
Basic igneous	36	Coarse grained igneous rocks with relatively low silica content, such as gabbro and diorite
Ultrabasic	37	Peridotite, dunite, serpentine, pyroxene and metabasalts
Mixed or undifferentiated igneous	38	Areas of igneous rock of either highly variable or unknown chemical composition
Semi-consolidated		
Pyroclastics	46	All the fragmented volcanic material which has been blown into the atmosphere by explosive activity either liquid globules which solidify in the air or as solid fragments derived from the fracture of pre-existing rocks. The material is generally weakly consolidated and may be highly variable in character, ranging from fine grained (ash, tuff) to coarse grained (agglomerates, volcanic conglomerate), lahars (volcanic mudflows) and lava flows
Unconsolidated		
Volcano-alluvial deposits	45	Fluvially redistributed volcanic debris of consisting sand and gravel with minor silt and clay, and occasionally volcanic ash derived locally from recently active volcanoes
Overlain with recent ash	47	Unconsolidated fine grained material deposited as a result of recent (that is, within the last 10,000 years) volcanic explosions
Overlain with older ash	48	Unconsolidated fine grained material deposited as a result of older (more than 10,000 years) volcanic explosions

Table 60: Geology code, description and relationship to rock type

Lithology symbol	Lithology description	rock type
Ja	Dark grey shale, calcareous and sandy in part	11
Jaki	Dark grey mudstone and siltstone, interbedded fine micaceous quartz sandstone; and/or micaceous quartz sandstone, quartz sandstone; minor arkose, siltstone, mudstone	11
Jo1	Black carbonaceous siltstone and mudstone with concretions and black pyritic chert nodules and lenses; minor fine quartz sandstone; ammonites, bivalves, obelemnites	11
Jo3	Fine lithic sandstone	11
Jui	Dark grey mudstone and siltstone, interbedded fine micaceous quartz sandstone	11
Klt	Mudstone, minor siltstone, feldspathic sandstone, rare argillaceous limestone; mudstone is variably shaly, micaceous, glauconitic, carbonaceous, pyritic	11
KTa	Undivided Kuc2 and Ta1: calcareous shale and siltstone	11
KTe	Undivided Kuc2, Ta1, Temf3: calcareous shale, siltstone and fine limestone	11
KTw1	Argillite, shale, slate, siltstone, minor lithic and feldspathic sandstone, greywacke, rare conglomerate, limestone and interbedded spilitic volcanics	11
KTw2	Shale, siltstone, slate, minor lithic and feldspathic sandstone	11
Temf1	Dense foraminiferal micrite, fine grained calcarenite, chert nodules; minor grey siltstone, silty mudstone	11
Tmnm2	Mudstone	11
Tnf	Pale grey to brown foraminiferal micrite, fine grained calcarenite; rare chert nodules	11
Tng	Grey calcareous siltstone, silty mudstone	11
Tnm	Grey calcareous mudstone; interbedded siltstone	11
Tp-m1	Marine and terrestrial clastic sedimentary rocks, mostly fine grained; coal	11
Czm	Cobble and boulder conglomerate, pebbly sandstone	12
Czub	Calcareous cobble and boulder conglomerate, lithic coquinoid sandstone, siltstone	12
Jb	Conglomeratic arkose, very coarse arkose; minor quartzose sandstone at top	12
Jo2	Quartz sandstone	12
Jum4	Basal rudite, arkose	12
Kuc3	Clean quartz sandstone (thin lens)	12
Qpt	Crudely bedded, poorly sorted conglomerate, limestone clasts predominant; pebbly sandstone	12
Qpw	Carbonaceous and ferruginous gravel, yellow iron-stained micaceous sand, sandy clay, peat, pisolitic ironstone; some laterite: older terrace gravels	12
Tmbf1	Quartz pebble conglomerate and coarse sandstone, friable	12
Tmbf2	Dark volcanic sandstone, siltstone, polymict micaceous sandstone, some conglomerate and agglomerate, minor siltstone, rare limestone	12
TQu	Coarse angular to rounded unsorted polymict conglomerate with a kaolinized arkosic lithic sandstone matrix; some conglomeratic sandstone: fanglomerate	12
Jk	Micaceous quartz sandstone, quartz sandstone; minor arkose, siltstone, mudstone; rare ammonites	13
Jki	Dark grey mudstone and siltstone, interbedded fine micaceous quartz sandstone; and/or micaceous quartz sandstone, quartz sandstone; minor arkose, siltstone, mudstone	13

Lithology symbol	Lithology description	rock type
JKt	Fine to medium clear quartz sandstone, variably glauconitic; minor mudstone, siltstone, bioturbated micaceous sandstone	13
Jlb	Greenish grey polymict lithic quartz sandstone, red siltstone	13
Jlg	Calcareous and volcanolithic greywacke, sandstone, siltstone; minor shale	13
Jum1	Indurated shale and siltstone; some sandstone, limestone, shale	13
Jum2	Arkose, breccia and conglomerate at base	13
Jum3	Dark calcareous siltstone and shale, part carbonaceous, some pyrite; rare thin beds fine quartz sandstone, minor calcilutite; characteristic bivalve fossils (Malayom)	13
Kie	Silty polymict blue and greenish grey fine glauconitic quartzose sandstone and siltstone, recessive grey glauconitic mudstone and siltstone	13
Kl	Lithic sandstone, interbedded siltstone and mudstone; minor greywacke and limestone	13
KTf1	Fine grey sandstone, siltstone, shale; clean and muddy quartz sandstone and quartzite, partly glauconitic; belemnites, ammonites, rare limestone	13
KTf2	Quartz sandstone, quartzite, partly glauconitic, pyritic where hornfelsed	13
Kuc5	Shale, siltstone, sandstone; minor calcarenite, greywacke, conglomerate, tuff, altered volcanics	13
Kus	Red and grey mudstone, slate, phyllite, calcareous schist; (part of Auga Beds?)	13
Qa10	Weakly or moderately lithified conglomerate, sandstone, siltstone, mudstone: older alluvium, lake deposits, includes some Qs2	13
Qa14	Conglomerate, sandstone, mudstone; older alluvium	13
Qa7	Conglomerate, sandstone, mudstone; alluvium	13
Qa8	Weakly lithified older alluvium	13
Qgm1	Gravel, breccia: moraine and fluvioglacial deposits	13
Qgm2	Boulder beds, poorly sorted, crudely bedded gravel, sand, silt, clay; fluvioglacial deposits	13
Qgm3	Poorly-sorted unconsolidated glacial moraine deposits	13
Qgm4	Scattered gravel, breccia over Qvg4 (Giluwe Volcanics): moraine	13
Qp	Coarse unsorted conglomerate near Wau and fluvial sediments of coastal plains and Lakekamu Embayment	13
Qpa	Tuffaceous and calcareous sand and gravel: lacustrine deposits	13
Qpac	Conglomerate, sandstone, siltstone; poorly consolidated: former alluvium	13
Qpar	Conglomerate, sandstone, siltstone; poorly consolidated: former alluvium	13
Qpaw	Sandstone, conglomerate, siltstone, mudstone; minor thin lignite seams, tuff, agglomerate, white sandy clay: mostly former alluvium	13
Qpc	Poorly sorted conglomerate and agglomerate; mud-flow deposits?	13
Qpkw	Conglomerate, poorly sorted sandstone, siltstone, marl: mostly non-marine	13
Qpm	Poorly consolidated sandstone, siltstone, carbonaceous mudstone,some limestone, conglomerate: raised alluvium and littoral deposits, partly marine	13
Qpr	Fluviatile conglomerate, sandstone and mudstone, partly tuffaceous	13
Qps1	Conglomerate, sandstone, siltstone; poorly consolidated: former alluvium	13
Qst4	Terrestrial clastic sediments, lignite	13
Ta1	Calcareous shale, siltstone, minor limestone, polymict green, grey sandstone; phyllitic and subschistose in part (Tsak valley)	13

Lithology symbol	Lithology description	rock type
Ta2	Grey to green calcareous, glauconitic sandstone, siltstone; and/or soft, grey foraminiferal calcareous mudstone, minor quartz sandstone, siltstone interbeds	13
Tae	Undivided Ta1 and Temf3: grey calcareous shale, fine limestone, very fine sandstone	13
Tam	Soft, grey foraminiferal calcareous mudstone, minor quartz sandstone,siltstone interbeds interbeds	13
Tap	Sandstone, tuff, siltstone, mudstone; minor conglomerate	13
Tau	Grey to green calcareous, glauconitic sandstone, siltstone	13
Tb	Sandstone and siltstone composed of volcanic material; agglomerate, tuff, basalt	13
Teb	Calcilutite, siltstone, sandstone, minor chert; well bedded	13
Tlm	Sandstone, siltstone, mudstone, conglomerate, agglomerate	13
Tmac	Polymict conglomerate; some conglomeratic silty lithic sandstone, pebbly limestone	13
Tmau3	Greywacke, siltstone, pebbly sandstone, shale	13
Tmau6	Greywacke, siltstone, mudstone; minor pebble conglomerate; calcareous interbeds, lignite bands and carbonaceous lamellae	13
Tmde	Tuffaceous sandstone	13
Tmif	Grey and black calcareous mudstone, siltstone, silty quartz sandstone; rare lignite	13
Tmls1	Grey calcareous siltstone and mudstone; part limestone-shale interbeds; part tuffaceous	13
Tmls2	Grey and blue mudstone and siltstone, fine calcareous sandstone (Lai Siltstone?)	13
Tmlv1	Calcareous tuffaceous sandstone, conglomerate, lenses of biohermal limestone and reef debris, minor siltstone and mudstone	13
Tmm	Tuffaceous siltstone, sandstone, pebble and cobble conglomerate, paraconglomerate, mudstone; minor intercalated tuff, agglomerate, volcanogenic bentonite; rare ligni	13
Tmn	Calcareous and non-calcareous siltstone; minor mudstone and tuffaceous sandstone	13
Tmo1	Calcareous siltstone, shale and sandstone; minor conglomerate	13
Tmo3	Volcanolithic and calcareous sandstone, siltstone and shale, conglomerate; some tuff; minor chert	13
Tmpd	Tuffaceous sandstone	13
Tmq	Sandstone and siltstone; tuffaceous, partly carbonaceous, well bedded, poorly sorted	13
Tmr	Well-bedded, tuffaceous, calcareous lithic sandstone and siltstone, conglomerate interbeds; coarse volcanic conglomerate at base	13
Tmrs	Lithic sandstone, polymictic conglomerate, siltstone; some silty claystone and tuff	13
Tmsc	Polymictic orthoconglomerate, sandstone, siltstone, mudstone; moderately consolidated	13
Tmss1	Polymict conglomerate, sandy conglomerate, lithic sandstone, sandy siltstone, planktonic foraminiferal siltstone, pebbly siltstone, graded silty sandstone and sandy	13
Tmss2	Polymict conglomerate, sandy conglomerate, conglomeratic silty lithic sandstone, some very fine sandstone, sandy siltstone	13
Tmsw3	Dark micaceous polymict poorly-sorted sandstone and muddy sandstone, thick-bedded, homogeneous; conglomerate at base	13
Tmsw5	Silty micaceous lithic sandstone, thick-bedded, homogeneous	13

Lithology symbol	Lithology description	rock type
Tmud1	Mudstone, shale; minor thin interbeds of siltstone, sandstone, limestone and conglomerate; volcanic interbeds towards base	13
Tmup1	Mudstone, siltstone, minor sandstone, rare conglomerate, calcarenite; generally carbonaceous, calcareous in places	13
Tmup2	Blue-grey calcareous mudstone, shale; interbeds siltstone, sandstone	13
Tmup3	Mudstone; some siltstone, sandstone; minor calcareous sandstone	13
Tmyf1	Tuffaceous sandstone, pebble and cobble conglomerate, siltstone, mudstone, claystone	13
Tmyf2	Volcanic conglomerate, tuffaceous sandstone, minor siltstone; moderately consolidated	13
Tmz	Laminated grey siliceous siltstone and brown claystone; minor thin beds of glauconitic silty sandstone	13
Tou1	Shale, siltstone, feldspathic sandstone	13
Tp	Interbedded calcareous mudstone, micaceous siltstone some thin sandstone, conglomerate	13
Tp?	Interbedded calcareous mudstone, micaceous siltstone; some thin sandstone, conglomerate	13
Tpa	Poorly consolidated sandstone, siltstone, conglomerate	13
Tpab	Semiconsolidated marine volcanolithic sandstone, siltstone, mudstone and conglomerate, calcareous in part	13
Tpbf	Sandstone, conglomerate, tuff, agglomerate, marl near base minor lignite near top: mostly former alluvium	13
Tpbo	Interbedded sandy siltstone, very fine sandstone, siltstone; minor coarse lithic sandstone, sandy conglomerate; minor limestone	13
Tpc	Polymict conglomerate, sandy conglomerate, pebbly silty lithic sandstone;some siltstone, sandy siltstone, pebbly siltstone	13
Tpcv2	Tuff and tuffaceous sandstone	13
Tpe	Calcareous tuffaceous sandstone, siltstone, mudstone; minor paraconglomerate, pebble conglomerate.	13
Tpgw	Micaceous sandy siltstone, shelly planktonic foraminiferal silty mudstone; minor fine to medium calcareous silty sandstone	13
Tpif1	Blue calcareous mudstone, siltstone, marl with small concretions; some silty lithic sandstone, sandy conglomerate	13
Tpif2	Blue marl, marly sandstone, calcareous sandy siltstone with small concretions; minor polymict conglomerate, pebbly lithic sandstone	13
Tpif3	Polymict conglomerate, coarse pebbly lithic sandstone; minor blue marly very fine sandstone with small concretions	13
Tpk1	Well-bedded, cross-bedded, calcareous, lithic arenite, siltstone and mudstone. Conglomerate (some very coarse), interbedded biomicrite, basalt and andesite lava	13
Tpk2	Well-bedded, cross-bedded calcareous lithic arenite, siltstone and mudstone, conglomerate and pebble conglomerate, minor lignite	13
Tpk3	Biomicrite, micrite, calcilutite	13
Tpkb	Calcareous mudstone, micaceous siltstone, interbedded; some thin sandstone, conglomerate	13

Lithology symbol	Lithology description	rock type
Tpkp	Semi-consolidated massive to well-beddedacid tuffacaeous sandstone, siltstone and conglomerate, tuff, volcanolithic conglomerate, calcareous sediments, limestone	13
Tpks	Sandstone, conglomerate, siltstone, claystone	13
Tpku1	Sandstone, shelly sandstone, siltstone, mudstone, minor conglomerate	13
Tplc	Conglomerate; minor agglomerate, tuff, silty sandstone	13
Tple1	Greywacke, lithic arenite, pebbly lithic arenite, conglomerate (some very coarse), siltstone, minor limestone, lignite	13
Tple2	Bedded sandstone, pebbly sandstone and conglomerate, siltstone; minor lignite	13
Tple4	Conglomerate; basalt and andesite clasts predominant; crudely bedded, poorly sorted	13
Tpls	Lithified sandstone, siltstone and conglomerate	13
Tplu	Polymict conglomerate, sandy conglomerate, conglomeratic lithic sandstone, sand siltstone, shelly siltstone, medium to fine silty sandstone; minor carbonaceous muds	13
Tpm	Medium to coarse silty sandstone, pebbly sandstone, fine polymict conglomerate, sandy siltstone, pebbly siltstone	13
Tpnn1	Alternating mudstone and sandstone, siltstone, blue-black fissile mudstone, conglomerate, pebbly mudstone	13
Tpnn2	Mudstone; some interbedded sandstone; minor fine conglomerate near base	13
Tpnn3	Interbedded mudstone, siltstone, fine lithic sandstone; passing up into sandy polymict conglomerate, lithic sandstone, sandy siltstone	13
Tpnn4	Smoky blue-black micaceous mudstone; minor grey-green mudstone; sandstone	13
Tpom	Calcareous siltstone, mudstone, pebbly siltstone, fine carbonaceous silty sandstone, sandy siltstone; minor fine polymict conglomerate, sandy conglomerate	13
Tprc	Conglomerate, poorly sorted sandstone and siltstone	13
Tpsf	Planktonic foraminiferal siltstone, mudstone; some interbedded siltstone, very fine silty sandstone; minor pebbly siltstone	13
Tpts	Poorly consolidated sandstone, conglomerate and siltstone, with shelly interbeds	13
Tpu	Medium to fine silty sandstone with platy calcareous concretions; interbeds of siltstone, mudstone	13
Tpus	Poorly consolidated cross-bedded sandstone, siltstone, minor conglomerate	13
Tpwc	Claystone, laminated white marl; some sandstone, siltstone, conglomerate	13
Tpwe	Calcareous siltstone, sandy siltstone, pebbly siltstone, silty lithic sandstone, polymict conglomerate, sandy conglomerate	13
Tpws	Green-black sandstone, minor conglomerate, siltstone, grey shale; calcareous near base, tuffaceous, partly carbonaceous, lignite near top	13
Tpx	Smoky blue-black micaceous mudstone and siltstone; some silty lithic sandstone, conglomerate	13
Tpx?	Smoky blue-black micaceous mudstone and siltstone; some silty lithic sandstone, conglomerate	13
TQb	Conglomerate, conglomeratic sandstone, blue-green siltstone and mudstone with brecciated concretions; minor lignite	13
Tpw	Conglomerate, sandstone, minor siltstone, mudstone, weakly consolidated	13

Lithology symbol	Lithology description	rock type
TQn1	Silty lithic sandstone, sandy siltstone, siltstone; minor conglomerate, calcareous sandstone, lignite	13
TQn2	Carbonaceous silty pebbly lithic sandstone, sandy siltstone; minor lignite	13
TQn3	Fine sandstone, siltstone, mudstone	13
TQs	Mudstone, sandstone, gravel	13
TQw1	Carbonaceous silty lithic sandstone, siltstone, mudstone: minor thin lignite seams	13
Kn	Marl, impure limestone; fine-grained, sediments mostly calcareous; weakly metamorphosed in places	14
KTo	Undivided Kuc2, Ta1, Temf3, Tomk1, Tomk2: calcareous shale, siltstone, and fine limestone	14
KTq	Strongly sheared undivided Kuc2, Ta1, Temf3	14
KTs1	Red and green siltstone, shale, lithic sandstone, limestone, volcanics	14
Kuc4	Massive dark grey calcareous shaley mudstone; fine grained laminated sandstone, siltstone, shale, minor calcarenite	14
Kuk	Fine feldspathic, glauconitic sandstone, siltstone, mudstone; interbedded silty argillaceous limestone	14
KuTa	Carbonaceous shale, slate, argillite, mudstone, lithic greywacke, siltstone; minor conglomerate, limestone, calcarenite	14
Te1	Calcarenite, minor micrite, calcareous mudstone, rare chert, glauconitic sandstone, claystone, and shelly calcirudite	14
Te2	Limestone, calcareous mudstone, calcarenite, sandstone; siltstone	14
Temf2	Glauconitic, calcareous quartz sandstone	14
Temf3	Dense yellow-grey or brown-grey micritic limestone, fine calcarenite, minor siltstone and calcareous quartz sandstone (Mendi Formation?)	14
Ten	Micrite and fine calcarenite, partly re-crystallised	14
Teoc	Grey buff and white foraminiferal limestone, calcarenite, siltstone	14
Teom	Shear zone, includes rafts of Tes and Tomx	14
Teon	Grey limestone and calcarenite: minor argillite, siltstone	14
Tep1	Siliceous argillite, shale, calcilutite, minor chert, calcarenite; undivided	14
Tep2	Massive argillaceous biomicrite	14
Tep3	Partly calcareous, siliceous argillite and shale, calcilutite, chert, minor calcarenite and dolomite	14
Tep4	Calcarenite, minor calcirudite; glauconitic	14
Tep5	Partly calcareous argillite and shale, calcilutite, minor tuff and slump breccia	14
Tes	Massive algal foraminiferal biosparite, detrital limestone, calcareous sandstone, pink siliceous limestone, chert, black massive and slatey siltstone; grey recrystal	14
Tmau1	Greenish grey greywacke, sandstone, dark grey calcareous mudstone, siltstone, minor conglomerate, limestone	14
Tmau5	Volcanically derived greywacke and siltstone; minor marl, calcareous siltstone, argillaceous limestone, tuffaceous greywacke, conglomerate: geosynclinal facies	14
Tmaw	Calcareous mudstone and siltstone; minor limestone, some glauconite	14
Tmd1	Massive to thick bedded limestone; white to cream algal foraminiferal biomicrite, calcarenite, calcirudite, calcilutite, blocks of coralgal biosparite, minor dolomit	14
Tmer1	Limestone; tuffaceous sandstone	14

Lithology symbol	Lithology description	rock type
Tmer2	Graded bedded tuffaceous sandstone and siltstone, minor limestone	14
Tmg1	North: conglomerate and sandstone, interbedded marl, mudstone,calcarenite: shelf facies. South: silty mudstone and siltstone, sandstone, grit, conglomerate: shelf	14
Tmla	Well-bedded calcareous, tuffaceous, lithic sandstone and siltstone, mudstone, pebble conglomerate, some intercalated limestone; basalt dykes and flows	14
Tmlv2	Coralgal limestone with calcareous sandstone, calcirudite, breccia, siltstone and mudstone	14
Tmmu	Massive and crudely bedded algal-foraminiferal biomicrite, some well-bedded calcareous sandstone and minor conglomerate at base; calcarenite, calcilutite	14
Tmp1	Soft, white to brownish white biomicrite, calcarenite, calcilutite; lignite and calcareous conglomerate at base in places	14
Tmp2	Soft white to brownish white fossiliferous micritic limestone, thin lignite, calcareous shale; siltstone and fine sandstone at base	14
Tmpb1	Globigerina limestone, globigerina marl, limestone and marl conglomerate;some silty lithic sandstone, planktonic foraminiferal siltstone; minor coralline limestone	14
Tmpe	Soft calcareous shale and siltstone; subordinate soft porous limestone	14
Tmpf1	Soft grey calcareous mudstone and siltstone with limestone interbeds	14
Tmpf3	White fossiliferous limestone, partly tuffaceous with marl interbeds	14
Tms	Biohermal limestone grading laterally into marl, limestone with some siltstone, sandstone and conglomerate: shelf facies	14
Tmtm	Dark grey marl and shale, interbedded limestone, thin sandstone and conglomerate lenses	14
Tmud2	Marl, mudstone, siltstone with interbeds of sandstone, limestone, conglomerate	14
Tmup4	Calcareous mudstone and siltstone, minor limestone; part tuffaceous	14
Tmx	Thin-bedded limestone, mudstone, siltstone and sandstone interbeds	14
Tmy2	Soft calcareous siltstone, sandstone and mudstone with interbedded limestone	14
Tmy3	Bioclastic limestone with thick interbeds of clayey biomicrite and chalky limestone	14
Tmy4	Compact or porous massive to well-bedded bioclastic limestone, chalk, calcareous siltstone and mudstone; minor calcirudite	14
Tmy5	Coralline and algal calcarenite, calcilutite; minor calcirudite, calcareous siltstone, mudstone	14
Tna	Yellow to brown-grey argillaceous micrite, fine calcarenite, rare calcirudite	14
Tom	Reef limestone, recrystallized limestone, biosparite, partly argillaceous; discontinuous sandy siltstone, conglomeratic lithic sandstone at base	14
Tomk2	Soft grey siltstone, shale, marl, minor limestone	14
Tomx	Calcareous sandstone, limestone, pebble conglomerate	14
Tot	Indurated, veined, andesitic and basalt agglomerate and lapilli tuff, lava breccia and lava; indurated tuffaceous lithic greywacke; some limestone lenses near top	14
Tou-m1	Marine clastic sedimentary rocks and interbedded limestone, bioclastic limestone	14
Tou-m2	Mainly limestone. Marine clastic sedimentary rocks and interbedded limestone, bioclastic limestone	14
Tpbc	Polymict conglomerate; minor sandstone, calcareous mudstone, coralline limestone	14
Tpfu	Shelly siltstone, mudstone; some sandstone; minor limestone; undivided Tpl6, Tpg1	14

Lithology symbol	Lithology description	rock type
Tpj1	Soft calcareous siltstone, mudstone and sandstone with interbedded chalky limestone	14
Tpj2	Soft calcareous siltstone, sandstone, mudstone, conglomerate, limestone, shelly pumiceous siltstone	14
Tpob	Mudstone; minor sandstone, siltstone, mudstone, conglomerate limestone	14
Tppm1	Foraminiferal mudstone and siltstone with graded bedding, poorly consolidated silty sandstone; minor concretionary limestone and sandstone, conglomerate, shelly muds	14
Tppm2	Foraminiferal mudstone, foraminiferal siltstone, foraminiferal marl; some micaceous sandstone, marly sandstone; minor limestone and conglomerate; lignite seams	14
Tpr1	Foraminiferal mudstone, marl, siltstone with coquinal lenses, shelly sandstone; some conglomerate, coarse lithic sandstone; minor thin limestone; minor TQb	14
Tpsb	Soft calcareous siltstone and mudstone, calcilutite, bioclastic limestone lenses and interbeds	14
Tpwh	Coralgal limestone, calcareous sandstone, pebble conglomerate; minor calcareous mudstone, siltstone	14
Czp	Chalky limestone, foraminiferal calcarenite, coralline calcirudite	15
KTb	Limestone, calcilutite, shale, argillite, calcareous tuff, minor basalt	15
KTk7	Recrystallized laminated limestone	15
KTk8	White foraminiferal limestone	15
P-Rk	Limestone, sandy limestone; minor arkose	15
Qa15	Mainly limestone. Coral, alluvium	15
Qc1	Calcarenite, calcilutite, bioclastic calcirudite, calcareous mudstone, siltstone, sandstone and conglomerate: raised coral reefs, terraces and lagoons	15
Qc2	Reef limestone, biosparite, calcareous sand, conglomerate, beach rock: raised reef	15
Qc3	Raised coral reef	15
Qc4	Raised coral; some coralline calcirudite, Tridacna shells and minor oolitic limestone	15
Qc5	Cavernous coralgal limestone, biocalcirudite, biocalcarenite, biomicrite, raised reef and reef talus	15
Qc6	Coralgal biomicrite and biocalcirudite, biocalcarenite, calcareous mudstone	15
Qpf1	Bioclastic limestone including coralline and algal lime framestone, packstone, wackestone; calcareous mudstone, conglomerate	15
Qpf2	Reef wall facies limestone	15
Qpf3	Lagoonal facies limestone	15
Qpk	Coralgal biomicrite and biocalcirudite, biocalcarenite	15
Qpn	Massive and crudely bedded biocalcirudite, algal-foraminiferal biomicrite, biocalcarenite; dolomitic in places	15
Qprw	Reef limestone, biosparite, marly limestone, sandy limestone, minor marl, calcareous siltstone, tufa, mollusc shells, sharks teeth: older raised reef	15
Qsc	Slumped limestone slabs (Tmd6 equivalent?)	15
Qss	Coralline and shelly limestone	15
Qst1	Terrestrial clastic sediments, some marine sediments; raised coral reefs	15
Qst2	Mainly limestone. Terrestrial clastic sediments, some marine ediments; raised coral reefs	15

Lithology symbol	Lithology description	rock type
Qst3	Mainly limestone. Conglomerate, limestone, marl; raised coral reefs, coal	15
Qw1	Massive or crudely bedded cavernous biocalcirudite, calcarenite, calcilutite, calcareous mudstone, subordinate lithic arenite and conglomerate, clay	15
Qw2	Cavernous reef limestone interbedded with calcarenite and volcanically-derived sandstone	15
Tea2	Limestone lenses	15
Teg	Marl, calcilutite	15
Teh	Biocalcirudite, foraminiferal-algal biomicrite (Chimbu Limestone?)	15
Tej	Limestone, chert	15
Tetc	Red and green calcilutite, hematitic, foraminiferal	15
Tew2	Limestone; minor conglomerate	15
Tew4	Limestone	15
Tlb	Calcarenite, calcirudite, minor recrystallized argillaceous limestone	15
Tlk	Foraminiferal and coralline limestone	15
Tls	Limestone	15
Tm	Limestone, dolomite, cherty mudstone and marl	15
Tmad	Reef limestone, calcarenite	15
Tmau2	Limestone	15
Tmau4	Argillaceous micrite	15
Tmay3	Minor limestone lenses	15
Tmay4	Calcarenite	15
Tmbo	Reefal limestone, tuff, lapilli tuff, limestone breccia; locally cherty	15
Tmc	Shelly calcarenite, some micrite	15
Tmch	White and yellow coralline limestone, well-bedded, some interbeds foraminiferal limestone	15
Tmd2	Argillaceous biomicrite, micrite, minor calcareous mudstone, rare calcarenite	15
Tmd3	Argillaceous biomicrite, micrite, rare calcareous mudstone, calcarenite: basinal facies	15
Tmd4	Biocalcarenite, biomicrite, calcirudite, rare argillaceous limestone, chert nodules: shelf facies	15
Tmd5	Cream, buff, grey bioclastic algal limestone; includes calcarenite, micrite, calcirudite; part recrystallized; part massive, part bedded	15
Tmd6	Slumped limestone slab	15
Tmd7	Algal-foraminiferal biomicrite with sandy biomicrite and pelsparite near base; minor dolomite and rare chert	15
Tmd8	Algal foraminiferal biomicrite, some coral, partly hornfelsed	15
Tmdp	Reef limestone, sandy and pebbly limestone, biosparite; some biopelsparite, limestone grit; minor sandstone, siltstone	15
Tmg2	Biohermal limestone: shelf facies	15
Tmg5	Limestone lenses	15
Tmgi	Reefal limestone, calcarenite, calcirudite	15
Tmgk1	Algal foraminiferal biomicrite, calcarenite, calcirudite, calcilutite; thin conglomerate at base	15

Lithology symbol	Lithology description	rock type
Tmgk2	Massive algal-foraminiferal biomicrite, biocalcirudite; soft grey well-bedded calcarenite, calcilutite and calcareous mudstone at top	15
Tmgk3	Algal-foraminiferal biomicrite; resistant, crudely bedded or massive; minor calcarenite, calcilutite	15
Tmgk4	Biomicrite; well bedded, more porous and less resistant than Tmgk3	15
Tmhc	Reef limestone, calcarenite, basal conglomerate	15
Tmki	Biomicrite, well bedded	15
Tmlm2	Minor limestone lenses	15
Tmnm1	Massive grey recrystallized limestone	15
Tmo2	Limestone	15
Tmo4	Limestone	15
Tmpf2	Limestone interbeds	15
Tmpl	Coralgal limestone, calcarenite, calcirudite, calcilutite, algal foraminiferal biomicrite	15
Tmrb	Algal-foraminiferal, tuffaceous, detrital limestone, white, grey, pink	15
Tmsr	Fine calcarenite and interbedded calcilutite; well bedded, moderately sorted	15
Tmsu	Chalky limestone, clayey calcarenite and calcirudite; minor arenaceous limestone; rare calcareous and volcanolithic sandstone	15
Tmsw1	White algal-foraminiferal-coralline limestone, partly recrystallized	15
Tmu1	Mainly limestone. Marine clastic sedimentary rocks, mostly fine grained and calcareous	15
Tmu3	Mainly limestone. Agglomerate, lavas, tuff, limestone, marine clastic sedimentary rocks	15
Tmy1	Compact massive coral-algal limestone, calcarenite, calcilutite; minor calcirudite	15
Tof3	Minor limestone lenses	15
Toj2	Limestone lenses	15
Tok2	Limestone	15
Tomk1	Fine micritic limestone	15
Tou5	Limestone	15
Tou8	Reef limestone, calcarenite: shelf facies	15
Tpku2	Limestone	15
Tpl	White bioclastic limestone, some poorly consolidated with clay matrix	15
Tple3	Minor limestone lenses	15
Tpz	Well-bedded or massive biosparite, biopelsparite	15
TQl	Reef limestone, planktonic foraminiferal chalk, marl; minor calcareous siltstone at base	15
Tzl	Reef limestone, biopelsparite; some silty biomicrite	15
JKm	High grade metamorphics, some low grade	21
Jom1	Black carbonaceous schist, phyllite and slate with pyritic chert nodules, minor fine quartzite	21
Jom2	Fine quartzite and micaceous quartzite	21
Jom3	Black sericitic graphitic schist, carbonaceous phyllite, with pyritic chert nodules and lenses, minor fine quartzite; metadiorite dykes	21

Lithology symbol	Lithology description	rock type
Kb1	Calcite-quartz-sericite-chlorite-albite schist, variably schistose limestone; some hornfels	21
Kb2	Calcite-quartz-sericite-chlorite-albite schist, variably schistose limestone; some hornfels: dip slopes	21
Kb3	Hornfels	21
Kb4	Metamorphosed basalt, dolerite and ophitic gabbro, hornfels; some limestone interbeds: prehnite-pumpellyite and greenschist facies metamorphism	21
Kb5	Metamorphosed basalt, dolerite and ophitic gabbro, hornfels; some limestone interbeds: prehnite-pumpellyite and greenschist facies metamorphism: dip slopes, generall	21
Ke1	Massive green mafic schist derived from basalt, dolerite, gabbro, & volcanic sediment; minor calcareous & felsic schist or phyllite. Common minerals: albite, chlorit	21
Ke2	Metabasalt, meta-tuff, metagabbro, some calcareous schist; greenschist facies transitional to blueschist (lawsonite, some blue amphibole)	21
Kk1	Slate, phyllite, schist, minor gneiss; predominantly psammitic and pelitic metasediments, subordinate metavolcanics; typical minerals: quartz, albite, white mica, ch	21
Kk2	Medium to coarse schist; typical minerals quartz, albite, muscovite, epidote, garnet, blue-green amphibole; higher grade greenschist facies	21
Kk3	Leucocratic, felsic chlorite-muscovite-quartz-feldspar schist (low greenschist facies), some garnet-mica schist, minor metabasite	21
Kk4	Quartzite? Photo-interpreted massive unit forms rounded hills	21
Kk5	Quartzite, massive and thick bedded	21
Ko1	Schist, slate, phyllite, metagreywacke, conglomerate, argillite	21
Ko2	Recrystallized limestone	21
Ko3	Slate, phyllite, quartz sericite schist, quartz chlorite schist, greywacke, rare metamorphosed tuff	21
Ko4	Pebble conglomerate	21
Ko5	Argillite, indurated greywacke, grit and conglomerate, recrystallized limestone	21
Ko6	Marble	21
Ko7	Graphite-quartz-feldspar-mica schist with some metabasalt and marble; mostly greenschist facies; tourmaline, andalusite in north, some glaucophane, lawsonite in sout	21
Ko8	Very fine basic schist and quartz-calcite-sericite schist: greenschist facies metamorphism	21
KTam1	Phyllite, quartz-mica, quartz-epidote mica, garnet-mica schist; some shale, slate, limestone, marble, metavolcanics; minor amphibolite, gneiss	21
KTam2	White nummulitic limestone	21
KTam3	Mica schist and hornblende gneiss: mica schist with felspar and quartz, some garnet, sillimanite, staurolite; hornblende gneiss with plagioclase and quartz, some epi	21
KTam4	Mica schist and gneiss with hornblende, felspar, garnet, scapolite, etc; small bodies diorite, granodiorite	21
KTam5	Sericite schist, phyllite	21
KTam6	Garnet-pyroxene-amphibole gneiss with albite, sphene, quartz, apatite, pyrite: Sobomari complex	21

Lithology symbol	Lithology description	rock type
Ma	Layered sequence of quartzofeldspathic gneiss with 10 percent amphibolite and calcic gneiss; amphibolite facies	21
Mbb	Schist; some indurated siltstone, greywacke and arkose; minor gneiss, quartzite, hornfels	21
Md	Undifferentiated gneiss and schist, mostly quartzofeldspathic; includes some small granitic intrusions	21
Mg1	Quartz veined schist, schistose carbonaceous and calcareous siltstone, phyllite, hornfels; minor gneiss, amphibolite	21
Mg2	Marble	21
Mi	Layered sequence of amphibolite calcic gneiss and quartzofeldspathic gneiss; amphibolite facies	21
Mn	Quartzofeldspathic gneiss, some amphibolite and calcic gneiss, part migmatite, no consistent layering; amphibolite facies	21
Mp	Layered sequence of chloritic basic schist, calcic schist and quartz-feldspar-mica schist; greenschist facies	21
Mr	Leucocratic quartzofeldspathic gneiss with consistent layering; amphibolite facies	21
Mt	Massive amphibolite	21
KTs10	Green and red polymict lithic sandstone and minor conglomerate, part volcanogenic, weakly metamorphosed	22
KTs2	Andesitic porphyry, volcanogenic sandstone, radiolarian shale	22
KTs3	Red and green radiolarian siltstone and shale, some graded beds	22
KTs4	Weakly schistose green volcanolithic sandstone	22
KTs5	Strongly sheared undivided KTs7, KTs8, Kts9, Kts10, Kts11	22
KTs6	Hornfelsed fine calcareous sediment and limestone (inliers in Tmkb1); elsewhere undivided KTs7, KTs8, Kts9, Kts10, Kts11	22
KTs7	Red, red and white, grey indurated calcareous siltstone, minor micrite; part schistose	22
KTs8	Pink marl, volcanogenic siltstone	22
KTs9	Buff, white micrite, biomicrite, fossiliferous calcarenite, benthic forams, partly recrystallized	22
JTt	Predominantly coarse-grained mafic and ultramafic rocks; some diorite; minor serpentinite, dolerite, adamellite	23
Juk	Siltstone, greywacke, schistose indurated and phyllitic shale, phyllite; minor indurated calcareous sandstone	23
KTau1	Massive siltstone, indurated shale, calcareous subgreywacke, eldspathic sandstone, pebble conglomerate	23
KTau2	Massive algal foraminiferal biosparite, detrital limestone, calcareous sandstone, pink siliceous limestone, chert (mostly Eocene)	23
KTsm1	Basalt and andesite submarine lava, breccia and tuff; some limestone matrix; partly greenschist facies	23
KTsm2	Mafic schist, metamorphosed gabbro and peridotite, sericite schist, phyllite, lithic sandstone, stretched conglomerate: Hunstein complex	23
KTsm3	Buff, white micrite, biomicrite, fossiliferous calcarenite, benthic forams, partly recrystallized	23
KTsm4	Slate, phyllite, sericite schist, schistose lithic sandstone, conglomorate, volcanics, limestone	23

Lithology symbol	Lithology description	rock type
KTsm5	Green lithic sandstone, siltstone, green and red polymict conglomerate tuffaceous and volcanolithic, moderately schistose (Figi beds)	23
KTtb	Glaucophane-epidote schist, mica schist, some lawsonite-glaucophane metavolcanics and greenschist facies metagreywacke; minor allochthons eclogite; minor sheared sla	23
Ku	Ultramafic rock with cumulus texture; constituent minerals: olivine, pyroxene, chromite as cumulus phases, pyroxenes post cumulus; little or no plagioclase; some ser	23
Kub	Sheared pink biomicrite, minor calcareous shale	23
Kuc1	Massive shale; some laminated sandstone, siltstone and shale; minor tuff, altered volcanics, greywacke, calcarenite, conglomerate	23
Kuc2	Grey calcareous shale with minor limestone; grey micaceous mudstone and siltstone (Porgera); rare clean quartz sandstone	23
Mg3	Phyllite, slate, schist, carbonaceous siltstone, minor greywacke, quartzite, andesite hornfels; low grade metamorphics of mainly pelitic derivation, mostly black, qu	23
Mg4	Schistose carbonaceous siltstone, schist, hornfels; minor recrystallized limestone, quartzitex	23
Mk	Metabasalt and basic schist, basalt mylonite, contorted laminated grey limestone; greenschist facies	23
Pzo	Slate, phyllite, schist, indurated shale and siltstone; minor metagreywacke, basic metavolcanics, hornfels	23
Ter	Conglomerate with schist, quartz, metadolerite and basalt clasts, minor agglomerate	23
Tew1	Siliceous marl, chert	23
Tew3	Phyllitic shale and slate, sheared calcareous sandstone and conglomerate, agglomerate, siltstone; minor cherty mudstone	23
Tmcf	Greywacke, siltstone, mudstone; minor pebble conglomerate; increasingly calcareous towards top with minor limestone	23
Tmdt	Andesitic and basaltic vitric, crystal, lithic tuff, minor agglomerate; partly calcareous; strongly jointed	23
Tmdv1	Porphyritic hornblende andesite lava, pyroclastics, sediments; lava is red, purple, white; pyroclastics white, blue-green	23
Tmdv2	Hornblende andesite lava, pyroclastics, sediments; strong silicic, alunitic, argillic alteration; lava is grey, blue, pyroclastics grey, white, some massive sulphide	23
Tme1	Hornblende andesite porphyry, microdiorite	23
Tmf1	Biotite-hornblende-quartz microdiorite and porphyry, hornblende-quartz diorite and andesitic porphyry; propylitic, silicic and potassic alteration; disseminated Cu,	23
Tmf2	(Biotite-) hornblende-quartz diorite, diorite and andesitic porphyry, unaltered, acicular hornblende typical	23
Tmlm1	Micaceous sandstone, greywacke, lithic siltstone, conglomerate	23
Ton	Conglomerate, arkose, greywacke, siltstone	23
Tou4	Dark, fractured, algal-foraminiferal biomicrite, dark calcareous siltstone, shale, greywacke	23
Tou6	Shale, volcanically derived greywacke and siltstone; minor conglomerate: shelf facies	23
Tpfs	Quartz monzonite porphyry, quartz monzonite: mineralized	23

Lithology symbol	Lithology description	rock type
Tpi	Porphyritic microdiorite and feldspar porphyry	23
Tpibl	Porphyritic micromonzonite and microdiorite	23
Jmm	Basaltic agglomerate and pillow lava, conglomerate, feldspathic greywacke	30
Klk	Lithic sandstone or greywacke, tuffaceous sandstone, shale, siltstone; minor conglomerate, agglomerate, volcanic breccia, lava	30
Klkv2	Veined and strongly jointed basalt and andesite breccia, pillow lava, lava, indurated tuffaceous lithic greywacke, siltstone, tuff, agglomerate; metamorphosed in par	30
Klkv3	Basaltic agglomerate and pillow lava, volcanolithic conglomerate, amygdaloidal lava, indurated calcareous siltstone, lithic and feldspathic sandstone	30
Tea1	Massive spilitic basalt, dolerite; minor chert, siltstone, shale	30
Tega	Indurated, strongly jointed veined red and green cherty argillite, chert beds, tuffaceous and lithic greywacke; minor basalt and andesite flow breccia, pillow lava	30
Tk	Agglomerate, tuff; sandstone, siltstone and conglomerate composed of volcanic material; andesite, basalt, pillow lava	30
Tma	Green, grey, dark, thick-bedded, poorly sorted volcanic and polymict sandstone and muddy sandstone	30
Tmay1	Andesitic to shoshonitic agglomerate, welded tuff, andesitic and basic lava, tuff, volcanolithic conglomerate, greywacke	30
Tmay2	Volcanolithic conglomerate, greywacke, tuff	30
Tmg4	Volcanolithic conglomerate, silty sandstone, basaltic and andesitic agglomerate	30
Tmgc	Volcanic conglomerate and paraconglomerate, coarse volcanic lithic sandstone	30
Tmkc	Pebble and boulder conglomerate, partly volcanolithic, some basaltic and andesitic agglomerate, sandstone, siltstone, shale	30
Tmnf	Marine volcanic arenite and lutite with volcanic conglomerate interbeds	30
Tmtv	Andesitic to basaltic agglomerate, tuff, lava breccia, lava; intercalated volcanically derived conglomerate, sandstone, minor mudstone	30
Tok1	Zeolitic volcanic breccia, lapilli tuff and tuff, commonly maroon or green, basaltic and andesitic lavas, non-indurated marine sandstone and siltstone	30
Tok3	Massive to well-bedded, moderately indurated volcanic breccia, maroon tuff, lapilli tuff, volcanic sandstone, siltstone and conglomerate, basic to intermediate lavas	30
Tomb	Greywacke, argillite, volcanolithic conglomerate; minor basaltic lava pyroclastics, limestone lenses	30
Tomv1	Massive, moderately indurated, marine volcanic breccia and conglomerate, some volcanic arenite and tuff, minor lutite and subordinate lava	30
Tomv2	Massive to well-bedded, moderately indurated volcanic conglomerate and breccia, sandstone and siltstone, volcanic arenite and tuff; minor lutite, basic lava; carbona	30
Tou3	Tuffaceous shale and siltstone, greywacke, pebbly conglomerate, lithic sandstone; minor lava, pyroclastics	30
Tpkv	Andesitic agglomerate, tuff, and volcanic sandstone, minor marl	30
Tpna1	Calcareous and non-calcareous tuffaceous sandstone, pebble and cobble conglomerate, siltstone, mudstone; minor limestone, volcanic agglomerate, fine white and coarse	30
Tpna2	Tuffaceous sandstone, pebble and cobble conglomerate, siltstone, mudstone; minor volcanic agglomerate, fine white and coarse brown tuff and brecciated lava: fluvial	30

Lithology symbol	Lithology description	rock type
Tpna3	East: poorly consolidated conglomerate, sandstone, mudstone, tuffaceous sandstone, pyroclastics. West: sandstone, siltstone, mudstone, conglomerate, coral limestone	30
Tpsv	Basalt agglomerate, lava, tuff, minor volcanic sandstone; shoshonitic affinities; minor sediments; volcanic plugs	30
Czg2	Andesite	31
Czk	Andesite, tuff, agglomerate	31
Czl2	Andesite	31
Czo2	Andesite	31
Czt2	Andesite and dacite	31
Czu	Andesite, basalt, dacite, agglomerate, tuff	31
Czv	Volcanics	31
Ka1	Massive basalt, basalt and spilite lava and pillow lava, minor fine-grained calcareous sediments; epidote etc. alteration, metamorphosed near major faults; includes	31
Ka2	Basalt lava and pillow lava, some epidote, uralite, chlorite alteration; jointed	31
KTd	Chloritised amygdaloidal glassy basalt, andesite; submarine lava, breccia, agglomerate, tuff, basic dykes and small intrusions	31
KTk1	Basalt and pillow lava with gabbro and dolerite intrusives (dykes), minor calcilutite	31
KTk2	Basalt and pillow lava with gabbro and dolerite intrusives (dykes), minor calcilutite: Late Cretaceous?	31
KTk3	Basalt and pillow lava with gabbro and dolerite intrusives (dykes), minor calcilutite: Eocene?	31
KTk5	Basaltic lava, pillow lava and dykes, minor gabbro, microgabbro and ultramafics, some calcilutite, limestone, argillite, and tuffaceous arenite. Middle Eocene?	31
KTk6	Basaltic lava, pillow lava and dykes, minor gabbro, microgabbro and ultramafics, some calcilutite, limestone, argillite, and tuffaceous arenite	31
KTs11	Andesitic and basaltic? pillow lava, submarine lava breccia, agglomerate, tuff, commonly with marl or limestone matrix	31
Qbb	Basalt lava and pyroclastics, partly reworked	31
Qda4	Trachyandesite and olivine trachybasalt lava flows, part faulted	31
Qda5	Trachyandesite lava flows	31
Qda9	Probably trachyandesite lava: northeastern eruptive complex (airphoto interpretation)	31
Qgv	Basaltic andesite lava, some agglomerate, some rhyolite or dacite	31
Qiv	Porphyritic olivine tholeiite lava	31
Qkv1	Andesitic, dacitic, rhyolitic and basaltic lavas, pyroclastics and reworked pyroclastics; minor obsidian	31
Qpe	Porphyritic, vesicular basalt and andesite lava; shoshonitic affinities	31
Qpg	Andesitic ash	31
Qpl	Vesicular basalt and olivine basalt, basalt acid tuff in south	31
Qpmv	Basalt lava and tuff	31
Qpnv	Andesite, basaltic andesite; minor basalt and dacite flows, agglomerate, unconsolidated pyroclastics	31

Lithology symbol	Lithology description	rock type
Qpu	Andesite and basalt volcanics, including lava	31
Qr	Trachyandesite and trachybasalt? lamprophyric lava flows, cumulodomes; some tuff and agglomerate	31
Qrv	Pumiceous ash and minor lava	31
Quv	Basaltic and andesitic lava flows: shoshonitic affinities	31
Qva	Aphyric to porphyritic plagioclase-rich, leucocratic andesite or dacite lava and volcanic breccia	31
Qvb1	Basaltic (shoshonitic) and andesitic lava, agglomerate, tuff; minor derived volcaniclastic conglomerate, sandstone	31
Qvb2	Volcaniclastic basaltic and minor andesitic breccia; reworked agglomerate, tuff, intercalated volcanically derived conglomerate, sandstone: laharic deposits	31
Qvc	Basalt, andesite, dacite, volcanic arenite, volcanic rudite, rare dykes	31
Qvd1	Basaltic (shoshonitic) and andesitic lava, agglomerate, tuff; minor derived volcaniclastic conglomerate, sandstone	31
Qvd2	Andesite and basalt agglomerate, tuff, minor lava at central parts of cones; volcanic sandstone, conglomerate, and tuff on lower slopes and aprons	31
Qvg1	Trachybasalt and high-K olivine tholeiite lava flows and cumulodomes: shield volcano lavas	31
Qvv	Andesite, basaltic andesite; minor basalt and dacite flows, agglomerate, unconsolidated pyroclastics	31
Tlo	Andesite and basaltic andesite flows and tuffs, typically porphyritic; andesitic agglomerate, intrusive breccia	31
Tlv	Basalt and basaltic andesite flows and tuffs, typically fine grained; pillow lavas, agglomerate, volcanic conglomerate, medium-grained mafic intrusions; shale, chert	31
Tmbl	Basalt and basaltic andesite lava; some hornblende andesite in east	31
Tmfv	Andesitic lava, tuff, agglomerate	31
Tmg3	Basaltic and andesitic lava and pyroclastics at base: shelf facies	31
Tmia1	Basaltic tuff, mostly shallow marine, some sub-aerial	31
Tmia2	Augite-phyric basalt conglomerate, breccia and tuff, calcareous matrix; green tuff, agglomerate, siltstone; younger? poorly consolidated conglomerate and sandstone	31
Tmkw	Porphyritic basalt and basaltic lava	31
Tmsw4	Potassic basalt lava and lava-breccia, porphyritic	31
Tmt1	Andesitic and basaltic lava, agglomerate, tuff, minor pillow lava	31
Tmv1	Porphyritic basaltic andesite, dacite, agglomerate, lapilli tuff, lava, lava breccia, bentonite; minor intercalated volcanic conglomerate & sandstone	31
Tmv2	Quartz-pyrite-haematite-zeolite-alunite breccia: altered and brecciated porphyritic andesite, basaltic andesite, pyroclastics, lava, micromonzonite, microdiorite dyk	31
Tmyd1	Pyritic quartz-alunite-zeolite breccia; altered and brecciated porphyritic quartz micromonzonite, micromonzodiorite and andesite pyroclastics and lava	31
Tmyd2	Porphyritic quartz micromonzonite, micromonzodiorite, microdiorite, andesite	31
Tmyi	Quartz monzodiorite, quartz diorite, quartz monzonite, tonalite with porphyry phases of microdiorite, microtrondhjemite, quartz micromonzodiorite, quartz microdiorit	31
Tmzt	Monzonite, minor trachyandesite	31
Tof2	Basaltic lava, peperite, pyroclastics	31

Lithology symbol	Lithology description	rock type
Tof4	Basaltic lava	31
Toj1	Porphyritic andesitic and minor basaltic lapilli tuff, agglomerate; minor welded ash-flow tuff, amygdaloidal and pillow lava, lava breccia tuffaceous limestone	31
Tou7	Basalt: shelf facies	31
Tpb	Basic volcanics; mainly horizontal basalt flows	31
Tpcv1	Basaltic and andesitic agglomerate and lava: shoshonitic affinities; volcanic plugs	31
Tpd2	Basaltic agglomerate: shoshonitic affinities	31
Tpda1	Basaltic and minor andesitic agglomerate, tuff, lava, lava breccia, with intercalated volcanically derived conglomerate and sandstone increasing westward	31
Tpda2	Basaltic and minor andesitic agglomerate, tuff, lava, lava breccia; massive to vesicular olivine and augite-phyric basalt	31
Tpda3	Lavas and pyroclastic rocks of the Mount Cameron Range volcanic cone	31
Tpda4	Basaltic and minor andesitic agglomerate, tuff, lava, lava breccia; massive to vesicular olivine and augite-phyric basalt; Tpda4 is a photo-geologic sub-unit of Tpda	31
Tpda5	Basaltic and minor andesitic agglomerate, tuff, lava, lava breccia; massive to vesicular olivine and augite-phyric basalt; Tpda5 is a photo-geologic sub-unit of Tpda	31
Tpda6	Basaltic and minor andesitic agglomerate, tuff, lava, lava breccia; massive to vesicular olivine and augite-phyric basalt; Tpda6 is a photo-geologic sub-unit of Tpda	31
Tpda7	Basalt and minor andesite agglomerate, tuff, lava, lava breccia, partly reworked	31
Tpev	Porphyritic andesite	31
Tpf1	Basaltic and andesitic lava, agglomerate and tuff, some pillow lava, minor tuffaceous sedimentary rocks, many dykes	31
Tpf2	Welded basaltic agglomerate	31
Tpga	Dacite and andesite agglomerate; minor crystal tuff	31
Tpia	Basalt and andesitic agglomerate, minor tuff; tuffaceous sandstone and volcanic conglomerate at base	31
Tpk4	Basalt and basaltic andesite lava and breccia	31
Tpma	Trachyte, andesite and basaltic andesite lava and agglomerate	31
Tpv	Basic volcanics	31
Tpy	Basalt and andesite pyroclastics, minor lava: remnants of cappings	31
TQk2	Volcaniclastic andesitic and basaltic breccia; reworked agglomerate, tuff, minor intercalated volcanically derived conglomerate, sandstone: laharic deposits	31
TQvc	Andesitic and basaltic lava; minor tuff, agglomerate, derived sediments	31
Tv	Volcanics, including alkali-olivine basalt and andesite	31
Ct	Rhyolite welded tuff, hornfels	32
Tee	Andesitic and dacitic glassy tuff, breccia, lava, minor calcilutite, planktonic foraminifera	32
Tl	Andesitic and dacitic porphyries, some granodiorite, gabbro	32
Tmsw2	Green porphyritic dolerite, augite andesite, mostly massive; some tuff; zeolite and chlorite alteration	32
Toi2	Intrusive-extrusive complex of rhyolite, dacite, andesite and tuff, rhyodacite porphyry	32

Lithology symbol	Lithology description	rock type
Tpaa2	Andesitic and dacitic porphyry; phenocrysts are hornblende, plagioclase, minor pyroxene, rare biotite	32
Tpaa3	Andesitic and dacitic volcanic agglomerate, volcaniclastic sandstone and mudstone, crystal tuff	32
Tpmv	Dacite, rhyodacite, andesite, pumiceous tuff	32
Tpnv	Andesite lava with some rhyolite, dacite, trachyte, trachyandesite and olivine basalt; basaltic agglomerate	32
TpQk	Rhyolite, rhyolitic obsidian, andesite ashflow tuff and some basalt	32
Tpt	Porphyritic hornblende andesite and microdiorite	32
Tpta	Andesite agglomerate, lapilli tuff, tuff (partly reworked), some andesite lava	32
Tpuv	Andesite agglomerate, lapilli tuff, tuff including ash-flow tuff	32
TQk1	Fine grained trachyandesite lava and lava breccia, some andesitic agglomerate and tuff	32
Qe	Rhyolite pumice and obsidian, ashflow tuff; trachyte?, dacite?, minor dolerite	33
Qph1	Bedded tuff and agglomerate, part gently folded; older Lamington eruptives	33
Qph2	Basalt, andesitic and dacitic agglomerate, ash and lava	33
Qph3	Andesite, trachybasalt and dacite agglomerate, tuff and lava; Hydrographers volcano deposits	33
Qph4	Andesite, trachybasalt and dacite agglomerate, tuff and lava; Hydrographers volcano deposits; Qph4 is a photo-geologic sub-unit of Qph3	33
Qph5	Andesite, trachybasalt and dacite agglomerate, tuff and lava; Hydrographers volcano deposits; Qph5 is a photo-geologic sub-unit of Qph3	33
Qsa	Andesitic, basaltic and dacitic lavas and pyroclastics, andesite porphyry, microdiorite	33
Qvg2	Volcanogenic gravel, sand, silt, some lava flows: outwash fan	33
Qvg3	Chaotic deposit high-K olivine tholeiite lava clasts, lava part scoriaceous, part palagonitic: palagonitic breccia	33
Qvg4	Basaltic (shoshonitic) lava, ash, tuff, agglomerate	33
Qvg5	Volcaniclastic basaltic and andesitic breccia; reworked agglomerate, tuff; minor intercalated volcanically derived conglomerate sandstone: laharic deposits	33
Qvh1	Volcanic rock fragments in matrix of finer fragments, silt and mud, poorly sorted, lithified; tephra, some lava flows: lahar deposits and related alluvial outwash fans	33
Qvh2	Olivine trachybasalt lava, agglomerate, minor andesite lava, ash and volcanogenic sediments: basal volcanics	33
Qvh3	Olivine trachybasalt and minor andesite lavas, some pyroclastics: remnant of cone	33
Qvh4	Chaotic deposit angular rock fragments in finer matrix: lahar deposits	33
Qvh5	Basaltic to dacitic lava, agglomerate, tuff, conglomerate, lahar deposits	33
Qvh6	Hypabyssal intrusives	33
Qvi	Basaltic (shoshonitic) and andesitic lava, agglomerate, tuff; minor derived volcaniclastic conglomerate, sandstone	33
Qvk	Basaltic (shoshonitic) and andesitic lava, agglomerate, tuff; minor derived volcaniclastic conglomerate, sandstone	33
Qvl	Basaltic and andesitic lava, agglomerate, tuff; minor derived conglomerate, sandstone	33

Lithology symbol	Lithology description	rock type
Qvm1	Basaltic (shoshonitic) to andesitic lava, agglomerate, tuff, porphyritic microdiorite dykes	33
Qvm2	Volcaniclastic basaltic and andesitic breccia, reworked agglomerate, tuff; minor intercalated volcanically derived conglomerate, sandstone laharic deposits	33
Qvm3	Basaltic (shoshonitic) and andesitic lava, agglomerate, tuff; minor derived volcaniclastic sediments	33
Qvm4	Volcanic sandstone, conglomerate and tuff, minor agglomerate on aprons; clasts andesitic and basaltic in composition	33
Qvs	Basaltic (shoshonitic) and andesitic lava, agglomerate, tuff; minor derived volcaniclastic conglomerate, sandstone	33
Qvt	Lava, agglomerate, ash	33
Qvy	Dacitic and andesitic lava, pyroclastics, crystal tuff, agglomerate	33
Tpag	Basalt and minor andesite agglomerate and tuff, partly reworked	33
Tpvn	Volcanic breccia	33
Tpvv	Lavas(?) on summit of Mount Victoria (photo-interpreted)	33
TQsv1	Andesitic and basaltic(?) agglomerate, tuff, lava: old cone	33
TQsv2	Volcaniclastic andesitic and basaltic(?) breccia, reworked agglomerate, tuff; minor intercalated volcanically derived conglomerate, sandstone; exotic blocks of limes	33
Ka3	Basalt lavas and pillow lavas, massive basalt, red-brown calcilutite, micritic grey limestone	34
Klkv1	Basalt and andesite lava, lava breccia, pillow lava, agglomerate, tuff, conglomerate, greywacke, minor limestone	34
KTk4	Basaltic lava, pillow lava and dykes, minor gabbro, microgabbro and ultramafics, some calcilutite, limestone, argillite, and tuffaceous arenite: Late Cretaceous Age?	34
Tbv	Basic, intermediate and minor acid volcanics and volcanically derived sediments; dolerite; minor limestone lenses; commonly sheared and altered	34
Tebv	Massive indurated highly jointed basaltic or andesitic lava, agglomerate, conglomerate, volcanic breccia, arenite, minor lutite, tuff, hypabyssal rocks, basic to intermediate	34
Tmbi	Fossiliferous calcarenite with volcanic detritus, minor calcareous tuff	34
Tml	Mainly limestone. Tuff, lavas, agglomerate, limestone, marine clastic sedimentary rocks	34
Tm-p	Mainly volcanics. Limestone, volcanics	34
Tmrf	Andesitic and dacitic crystal - lithic tuff, volcanolithic arenite and lutite, foraminiferal marl and limestone	34
Tmsb	Andesitic lava, agglomerate, volcanolithic conglomerate and arenite, dense grey limestone	34
Tmt2	Basal conglomerate; clasts are limestone and volcanic rock	34
Tmu2	Mainly volcanics. Agglomerate, lavas, tuff, limestone, marine clastic sedimentary rocks	34
Tod	Basalt lava and pillow lava; minor tuff, limestone	34
Tof1	Basalt and andesite flow breccia, indurated tuffaceous lithic greywacke, lithic and crystal tuff, paraconglomerate, peperite and peperitic breccia, palagonite brecci	34

Lithology symbol	Lithology description	rock type
Tof5	Basic lava, flowÏ breccia, agglomerate, tuff, volcanically derived greywacke, sandstone and siltstone, limestone lenses	34
Tp-m2	Mainly volcanics. Lavas and pyroclastics, minor limestone	34
Cub	Leucocratic biotite granite, porphyritic biotite granite and adamellite	35
Czd	Microdiorite, diorite, monzonite, granodiorite, syenite, granophyre	35
Jlu	Granodiorite, diorite, aplite and dolerite dykes	35
Kle1	Microdiorite, dolerite, gabbro	35
Kle2	Diorite, microdiorite	35
KTm	Sheared weakly foliated metadiorite; some metagabbro and metagranodiorite; intruded by dolerite dykes	35
KTp	Crushed and mylonitized granodiorite, diorite, dolerite, amphibolite; orthogneiss; some schist, adamellite, porphyry dykes	35
KTt	Medium-grained gabbro, dolerite, diorite, monzonite; some granodiorite, adamellite; minor pegmatitic and porphyritic equivalents, serpentinite; commonly sheared	35
Kuv	Biotite hornblende granodiorite	35
Ky	Gabbro, diorite, granophyric tonalite: prehnite-pumpellyite facies metamorphism	35
Mjk	Gneissic granite	35
Ps	Pink granite; chlorite, calcite and sericite alteration	35
Puk	Granodiorite, tonalite; minor diorite, gabbro, aplite, pegmatite	35
Tei	Tonalite, some granophyric diorite	35
Tek1	Tonalite (quartz diorite): quartz-oligoclase/andesine-hornblende rock	35
Tek2	Augite tonalite and some diorite	35
Tek3	Tonalite: quartz-hornblende-plagioclase; augite tonalite; feeders for Tee	35
Tek4	Tonalite cuts Ka3 (Lokanu Volcanics) basalts	35
Tid	Diorite, porphyritic microdiorite	35
Tmh	Monzonite, granodiorite, diorite: Hunstein and Chambri stocks	35
Tmi	Diorite, monzonite, minor granodiorite, gabbro; dykes, small plutons and stocks	35
Tmin	Granodiorite, diorite, some porphyry: Nekiei batholith	35
Tmio	Diorite, tonalite, granodiorite, gabbro, porphyry, pyroxenite lamprophyre	35
Tmit	Granodiorite, diorite	35
Tmiu	Diorite, quartz diorite, porphyritic microdiorite	35
Tmiw1	Granodiorite, diorite; plagioclase-pyroxene porphyry with much opaques (Timun area)	35
Tmiw2	Granodiorite, diorite; felsic phase (airphoto interpretation)	35
Tmkb1	Diorite, quartz diorite, granodiorite, quartz gabbro, gabbro, pyroxenite, hornblendite, some diorite pegmatite and porphyritic microdiorite	35
Tmkb2	Diorite, granodiorite, some porphyry	35
Tmkd	Diorite, gabbro, tonalite, granodiorite; andesite porphyry, dolerite and basalt dykes; minor trachyandesite	35
Tmke	Gabbro, mangerite, granodiorite	35
Tmkg	Medium and coarse granite	35
Tmmd	Diorite, microdiorite, granodiorite; minor gabbro, rhyodacite, porphyry, monzonite; andesite and dolerite dykes	35

Lithology symbol	Lithology description	rock type
Tmmg	Granodiorite, adamellite; subordinate monzonite, diorite, hornblendite and pegmatite	35
Tmms	Syenite, monzonite, minor gabbro; trachybasalt, latite, sanidine melanite porphyry dykes	35
Tmnd	Medium to fine quartz diorite	35
Tmny	Diorite, granodiorite, some porphyry: Yuat North batholith and stocks	35
Tmod1	Diorite, monzonite	35
Tmod2	Diorite and porphyritic microdiorite, monzonite and granodiorite stocks; ? indicates photo-interpreted. Oveia Diorite equivalent	35
Tmsy1	Granodiorite, minor diorite, some gabbro	35
Tmsy3	Felsic phase (airphoto Interpretation)	35
Tmub	Porphyritic microdiorite	35
Tmum	Porphyritic hornblende microdiorite	35
Tmuy	Monzonite, porphyritic microdiorite, porphyry	35
Toma1	Granodiorite, tonalite, trondhjemite	35
Top	Hornblende granodiorite, slightly altered	35
Tpaa1	Quartz monzodiorite, quartz monzonite, diorite and microdiorite, granodiorite, granite, some porphyry, some volcanics	35
Tpam1	Monzonite, granodiorite, adamellite, fine-grained equivalents; minor tuff, agglomerate, lava	35
Tpam2	Skarn?	35
Tpbp	Microdiorite and micromonzonite porphyry stocks, lamprophyric dykes	35
Tpbq	Quartz monzodiorite, granodiorite, quartz monzonite.	35
Tpep	Biotite and hornblende dacite and andesite porphyry stocks and dykes	35
Tpg	Granodiorite, minor tonalite, adamellite and granite	35
Tpgb	Granodiorite	35
Tpgg	Granodiorite	35
Tmog	Gabbro, monzonite	36
Tmsy2	Gabbro, some diorite	36
Tmwg1	Gabbro, pyroxenite	36
Toi1	Tonalite, gabbro, diorite, granodiorite, adamellite, monzonite, mangerite; related porphyries and microplutonic rocks	36
Toi3	Leucogabbro, basic diorite, diorite, microdiorite, tonalite, granodiorite, monzonite and adamellite	36
Toma2	Gabbro, norite, diorite (mostly leucocratic), rhyodacite plugs	36
Tomd	Diorite, some gabbro, inliers of hornfels and chert	36
Tos	Gabbro, diorite and other acid differentiates to the west; fine-grained gabbro, dolerite and basalt to the east	36
Tpgm	Gabbro	36
Ts	Gabbro, andesitic porphyry, diorite	36
Tvd1	Diorite, some tonalite, monzonite, adamellite, rare porphyry	36
Tvd2	Adamellite	36

Lithology symbol	Lithology description	rock type
Tvd3	Diorite, gabbro	36
Qu	Ultramafic rock fragments in clay; ultramafic colluvium	37
Tmgs2	Dunite	37
Tmmb1	Dunite, serpentinite, minor pyroxenite	37
Tmwg2	Dunite	37
Tou2	Sheared serpentinite	37
Um1	Ultramafic rock with tectonite (metamorphic) texture; constituent minerals: olivine, enstatite, chromite, some serpentine; rocks are harzburgite and dunite with enst	37
Um2	Harzburgite, dunite, orthopyroxenite; pyroxenite commonly as veins; serpentinite	37
Um3	Ultramafics: dunite, harzburgite, wehrlite, enstatite pyroxenite, websterite	37
Um4	Peridotite, minor pyroxenite, gabbro; lherzolite with cumulus texture; mylonitic harzburgite; part serpentinised	37
Um5	Peridotite and sheared serpentinite; some has deformed igneous accumulative texture	37
Um6	Ultramafic and minor gabbroic rocks: tectonised lherzolite, some accumulate dunite, peridotite and gabbro; most strongly deformed, some mylonitised	37
Um7	Sheared serpentinite	37
Um8	Ultrabasic rocks; mainly peridotite and serpentinized peridotite	37
Um9	Gabbro, pyroxenite, dunite, peridotite, serpentinite, hornblendite, serpentinite breccia, chlorite schist	37
Qs4	Weakly lithified older colluvium	40
Qa1	Gravel, sand, silt, mud, clay: alluvium and beach deposits	41
Qa12	Older alluvium	41
Qa13	Alluvium, coral	41
Qa2	Gravel, sand, silt, mud; minor Qm1: alluvium	41
Qa3	Silt, sand, mud, clay, gravel: alluvium, fluvial deposits	41
Qa4	Gravel, sand, silt, mud, clay, peat: fluviatile, lacustrine valley fill deposits, alluvial plain deposits, volcanic ash deposits	41
Qa5	Gravel, sand, silt, mud, carbonaceous mud, clay, minor peat, alluvial soils: alluvium and littoral deposits	41
Qa6	Alluvium, swamp	41
Qa9	Clay, peat: alluvium, lacustrine deposits	41
Qf1	Clay, sand, silt, boulder gravel: alluvial fan deposits	41
Qf2	Chaotic boulder deposits, gravel, sand, silt, clay; fanglomerate	41
Qf3	Conglomerates and sands; alluvial sand deposits	41
Qha1	Gravel, sand, silt, clay, organic remains: alluvium and swamp deposits	41
Qha2	River gravels, sands and muds; active alluvium	41
Qhc	Angular rock fragments, clay matrix: chaotic scree deposits, colluvium	41
Qhl	Clay, silt, sand, gravel, peat: lake deposits	41
Qhm	Silt and mud: non-tidal fresh water swamp deposits	41
Qhu	Gravel, sand, silt, clay; some large sub-angular boulders	41
Qhx	Gravel, sand, silt, clay; some large sub-angular boulders	41

Lithology symbol	Lithology description	rock type
Qk	Light grey carbonaceous non-calcareous clay, volcanic and cherty lithic sand and tuff laminae, gravel bed; lacustrine deposits	41
Qphf	Conglomerate, gravel, sand, silt: piedmont-slope deposits	41
Qpnb	Gravel, sand, silt: older northern terrace gravels	41
Qpnk	Conglomerate, silt, sand, clay: lacustrine deposits	41
Qs1	Chaotic deposits of angular rock fragments, gravel, sand, some clay; landslide debris: colluvium	41
Qs2	Chaotic deposits of angular rock fragments; slumped slate and shale: colluvium, minor alluvium	41
Qs3	Boulder gravel, clay, soil: scree deposits	41
Qs3/Tmo3	Boulder gravel, clay, soil: scree deposits	41
Qc7	Calcareous sands and shingle: cay and beach deposits	42
Qm1	Sand, silt, clay, minor gravel; beach rock: beach sand, chenier plain	42
Qm2	Coastal mud, beach sand	42
Qa11	Carbonaceous mud, minor reefal limestone, coral sand: alluvium, littoral deposits	43
Qa16	Alluvium, swamp, beach deposits	43
Qh	Clay, silt, sand, gravel; some coral	43
Qhs	Silt and mud: mangrove and tidal swamp deposits	43
Czb	Andesite, tuff, agglomerate, derived fan deposits	45
Cze	Andesite, basalt, agglomerate, tuff, derived fan deposits	45
Czl1	Undifferentiated agglomerate, tuff, andesite (?), derived fan deposits	45
Czmv	Tuff, agglomerate, andesite (?), derived fan deposits	45
Czn	Tuff, agglomerate, andesite (?)	45
Czo1	Undifferentiated andesite, pyroclastics, derived fan deposits	45
Czr	Andesite, pyroclastics, derived fan deposits	45
Czt1	Undifferentiated tuff, agglomerate, andesite, derived fan deposits	45
Qab	Fanglomerate and raised boulder beds	45
Qav	Volcanic outwash and minor primary ash	45
Qb	Chaotic deposits of angular fragments of ultramafic rock, some clay; mostly lithified: ultramafic colluvial breccia	45
Qda3	Coarse gravel, sand, silt, mostly volcanogenic, some tephra: old outwash fan	45
Qda8	Blocks of lava, coarse gravel, sand, silt: catastrophic flood deposit	45
Qpi	Ultramafic breccia: thick chaotic deposits	45
Qpip	Semi-consolidated fluviatile conglomerate, sandstone and siltstone; minor marine sandstone with molluscs	45
Qpma	Andesitic ash, minor agglomerate, some mudflow deposits	45
Qpo1	Conglomerate, sandstone, minor siltstone, mudstone, rare lignite; volcanically derived	45
Qpo2	Conglomerate, sandstone, minor siltstone, mudstone: terrace deposits	45
Qps2	Ultramafic breccia: thin planar sheets	45
Tmpi1	Poorly-semi consolidated marine and fluviatile arenite and lutite derived from acid and intermediate volcanism; minor conglomerate, some limestone	45

Lithology symbol	Lithology description	rock type
Tmpi2	Lava and ash flow tuff, welded tuff	45
Tmps	Subaerial lava, agglomerate and tuff, marine calcareous tuff	45
Tpo	Poorly consolidated tuffaceous siltstone, sandstone, conglomerate and tuff: lacustrine and fluviatile	45
Czg1	Undifferentiated pyroclastics and derived fan deposits	46
Qda1	Lahar and pyroclastic flow deposits, some coarse volcanogenic sediments: basal volcanics	46
Qda2	Trachyandesite lava, some pyroclastics and volcanogenic sediments: old cone	46
Qda6	Chaotic deposit of clasts of lava, finer volcanic debris, clay: volcanic debris fan	46
Qda7	Chaotic deposit of angular clasts of lava, mostly altered: pyroclastic flow	46
Qfb1	Basalt lava and pyroclastics, lahars, reworked pyroclastics	46
Qfb2	Dacite lava and pyroclastics, lahars, reworked pyroclastics	46
Qg	Basaltic and andesitic lavas, pyroclastics and reworked pyroclastics	46
Qhw	Dacite lava and pyroclastics	46
Qkv2	Lava, pyroclastics, reworked pyroclastics, superficial ash and pumice	46
Qkv3	Basaltic to rhyolitic pyroclastics, principally ash, lapilli, scoria and rubble, andesite, basalt, dacite, rhyolite extrusives, hypabyssal intrusives	46
Qt	Volcanic ash, some coarser pyroclastics: tephra	46
Qtv	Obsidian, pitchstone and rhyolite lava, pumiceous pyroclastics; partly reworked	46
Qv1	Mainly volcanics. Predominantly andesitic pyroclastic rocks and lavas; basalts, dacites, and rhyolites	46
Qv2	Mainly volcanics. Predominantly andesitic pyroclastic rocks and lavas; basalts, dacites, and rhyolites	46
Qv3	Basic to intermediate lavas and pyroclastic rocks (shoshonitic and calc-alkaline), lahars, fanglomerate, lacustrine deposits	46
Qv4	Mainly volcanics. Predominantly andesitic pyroclastic rocks and lavas; dacites, basalts and rhyolites	46
Qv5	Mainly volcanics. Lavas, tuff	46
Qvr	Lava, pyroclastics, reworked pyroclastics; mainly basalt	46
Qz	Andesitic pyroclastics	46
Tmek	Basalt and andesite pyroclastics, lava, volcanic sandstone	46
Tpp1	Acid and intermediate pyroclastics and lavas, porphyritic dacite or rhyolite plugs	46
Tpp2	Volcanolithic conglomerate	46
TQp	Probably pyroclastics, jointed and faulted (airphoto interpretation)	46
Qhn1	Ignimbrite; pyroclastic flow deposits, 1951 eruption	47
Qhn2	Andesitic ash and agglomerate	47
Qhn3	Andesitic agglomerate, tuff and lava forming the cone of Lamington; outlier of tuff	47
Qhn4	Andesitic agglomerate and tuff and waterlaid deposits; Lamington cone volcanic apron	47
Qhwv	Andesitic ash and agglomerate	47
Qmv	Rhyodacite and rhyolite ash and lava; dissected ash cones, tholoids, ash-flow tuff and ash-flow deposits	47

Appendix 3

10 Generalized relationship between landform, rock type, mean annual rainfall, slope, inundation and soil class

Landform type	Rock type	Mean annual rainfall (mm)	Landform element	Slope (°)	Inundation
RECENT LITTORAL LANDFORMS					
Mangrove swamps	Estuarine deposits	1000 - 7000	Upper and lower flats	<1	Tidal flooding
Estuarine plains alluvial deposits	Estuarine deposits,	1000 - 7000	Upper flats	<1	Near permanent inundation
Beach ridges and beach plains	Marine sands	1000 - 2000	Lower flats	<1	Tidal flooding
			Ridges	<1	No flooding or inundation
			Swales	<1	Periodic brief flooding or waterlogged
			Plains	<1	No flooding or inundation
		2000 - 4000	Ridges	<1	No flooding or inundation
			Swales	<1	Waterlogged or long term inundation
			Plains	<1	Waterlogged or long term inundation
Undifferentiated coastal plain alluvial deposits	Estuarine deposits,	1000 - 2000	Alluvial plains	<1	No flooding or inundation
			Mangrove flats, tidal flats	<1	Tidal flooding with freshwater inundation
		>2000	Mangrove flats, tidal	<1	Tidal flooding with freshwater inundation flats
			Raised coral reefs	<1	No flooding or inundation
			Alluvial plains	<1	variable
			Freshwater to brackish swamps	<1	Waterlogged or near permanent inundation

10. Generalized relationship between landform, rock type, mean annual rainfall, slope, inundation and soil class

Landform type	Rock type	Mean annual rainfall (mm)	Landform element	Slope (°)	Inundation
RECENT LITTORAL LANDFORMS					
Relict beach ridge complexes	Marine and alluvial sands	1500 - 2000	Beach plain, degraded beach ridges	<1	No flooding or inundation
			Swales	<1	Waterlogged
	Marine sands	2000 - 4000	Beach plain, degraded beach ridge	<1	Lower parts only waterlogged or long term inundation
Raised coral reefs	Limestone	<4000	Raised coral platform	<5	No flooding or inundation
		>4000	Raised coral platform	<5	No flooding or inundation
	Alluvial deposits	<2000	Floodplain	<2	Waterlogged,no flooding or inundation
		>2000	Floodplain	<2	Waterlogged, no flooding or inundation
RECENT FLUVIAL LANDFORMS					
Intricately dissected relict alluvial plain	Pleistocene sediments	1500 - 5000	Ridge crest, hillslopes	<20	No flooding or inundation
			Valley floors	<2	Near permanent or seasonal inundation
Little dissected relict alluvial plain	Pleistocene sediments	<2000	Undulating plain	<5	No flooding or inundation
			Depressions and valley floors	<2	Seasonal inundation
		4000 - 5000	Flat to gently undulating	<5	Lower parts only, long term inundation plains
Little dissected or undissected relict alluvial, colluvial and mudflow fans	Pleistocene sediments	<2000	Fan surfaces	<2	No flooding or inundation
			Shallow drainage depressions	<2	Waterlogged
	Alluvial	<2000	Fan surfaces	<2	Periodic brief deposits flooding or no flooding or inundation
		>2000	Fan surfaces	<2	Periodic brief flooding or no flooding or inundation

10. Generalized relationship between landform, rock type, mean annual rainfall, slope, inundation and soil class

Landform	Rock type	Mean annual type	Landform rainfall (mm)	Slope element	Inundation (°)
RECENT FLUVIAL LANDFORMS					
	Volcano alluvial	2000 - 4000	Fan surfaces	<5	No flooding or inundation
Dissected relict alluvial, colluvial and mudflow fans	Pleistocene sediments	1500 - 2000	Dissected fan surfaces	2-10	No flooding or inundation
		2000 - 4000	Dissected fan surfaces	2-10	No flooding or inundation
			Valley-side slopes	10-30	No flooding or inundation
	Alluvial deposits	2000 - 4000	Dissected fan surfaces	2-10	No flooding or inundation
			Valley-side slopes	10-30	No flooding or inundation
RECENT FLUVIAL LANDFORMS					
Narrow alluvial plains	Alluvial deposits	1500 - 5000	Floodplains	<2	Periodic brief flooding
			High terraces	<2	No flooding or inundation
Composite alluvial plains	Alluvial deposits	<2000	Floodplain	<2	Periodic brief flooding
			Back plains and back swamps	<2	Seasonal and long term inundation
		>2000	Floodplain	<2	Periodic brief flooding
			Back plains and back swamps	<2	Long term or seasonal inundation
				<2	Permanent inundation
Meander floodplains	Alluvial deposits	<2000	Scroll complexes and levess	<2	Periodic brief flooding
			Swamps, lakes, oxbows	<2	Seasonal or near inundation
		>2000	Scroll complexes and levess	<2	Long term inundation
			Swamps, lakes, oxbows	<2	Seasonal to permanent inundation

10. Generalized relationship between landform, rock type, mean annual rainfall, slope, inundation and soil class

Landform	Rock type	Mean annual type	Landform rainfall (mm)	Slope element	Inundation (°)
RECENT FLUVIAL LANDFORMS					
Composite levee plains	Alluvial deposits	1000 - 7000	Levee banks	<2	Long term inundation
			Back plains	<2	Long term or permanent inundation
Back plains deposits	Alluvial	1000 - 5000	Lower plains	<2	Seasonal to permanent inundation
			Higher plains and levees	<2	Long term inundation
Back swamps deposits	Alluvial	1000 - 7000	Deeper swampy floodplains	<2	Near permanent or permanent inundation
			Shallower swampy floodplains including levees	<2	Seasonal inundation
Blocked or drowned valley swamps	Alluvial deposits	1000 - 7000	Swampy floodplains and lakes	<2	Near permanent to permanent inundation
			Floodplain margins	<2	Near permanent or seasonal inundation
Undifferentiated swamps	Alluvial deposits	1000 - 7000	Deeper swampy plain	<2	Near permanent to permanent inundation
			Shallower swampy margins and plains	<2	Seasonal to near permanent inundation
Braided floodplain or bar plain	Alluvial deposits	<2000	Braided channel	<5	Periodic brief flooding (rare)
			Terraces	<2	Periodic brief flooding
		2000 - 4000	Braided channels and terraces	<2	Periodic brief flooding
Composite bar plain and complex alluvial fan	Alluvial deposits	<2000	Alluvial fan surface	<2	No flooding or inundation
			Bar plain	<5	Periodic brief flooding (frequent)

10. Generalized relationship between landform, rock type, mean annual rainfall, slope, inundation and soil class

Landform type	Rock type	Mean annual rainfall (mm)	Landform element	Slope (°)	Inundation
RECENT FLUVIAL LANDFORMS					
Little dissected recent alluvial fans	Alluvial deposits	>2000	Alluvial fan surface	<2	No flooding or inundation
			Bar plain	<5	Periodic brief flooding (frequent)
		<2000	Fan surface	<5	No flooding or inundation
		>2000	Fan surface	<2	Long term inundation
VOLCANIC LANDFORMS					
Volcano-alluvial plains	Volcano-alluvial deposits	2000 - 4000	Stable plains	0 - 2	No flooding or inundation
			Unstable bar or outwash plains	0 - 5	Periodic brief flooding
				0 - 2	Long term inundation
ALL OTHER LANDFORMS					
All other landforms					No flooding or inundation

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