

## 4. GEOGRAPHICAL INFORMATION SYSTEMS AND THE FIJI DATABASE

### 4.1. Principles of the geographical information system

A geographical information system (GIS) may be defined as a computer-based system (both hardware and software) for the capture, storage, integration, analysis and display of spatially distributed data. A GIS should be able to reference all data to defined map coordinates and manage changes of scale or geographic area; to transfer information to and from different sources and systems; to permit interrogation of the data (e.g. answer queries posed by the operator) usually through the use of a data base management system (DBMS), and to handle attribute information about an object (e.g. depth to named horizons in borehole logs). Importantly, it provides a means of visualising the data in various different ways and providing map outputs.

Conceptually, a GIS should be able to utilize spatial data in any form, whether raster, vector or tabular. (These are discussed further in Section 4.2). Most practical GISs, however, tend to operate predominantly with either raster or vector data, and this reflects fundamental differences in the way the GIS can be used. The benefits of both architectures are being increasingly recognized and systems are now available in which analysis and display can be performed in either mode.

By its nature, a GIS satisfies several important requirements for hazard mapping. These include:

- a database of spatially registered data which can be updated as new information becomes available;
- a capability to output simple thematic maps of selected parameters, at appropriate scales, tailored to meet particular user needs;
- an ability to compare and analyse inter-relationships between variables in order to 'model' the controls on hazards.

These will now be considered in turn.

**Database:** The establishment of a database, or inventory, of information relating to landslides is a major task involving various inputs. These may include remote sensing, lithological and soils information, structural, and geotechnical data, laboratory test results, and so forth depending on what data exist and are readily available. In many respects, the task of databasing is one that should be considered ongoing, more data being added as it becomes available. Given these requirements, some form of digital database is the obvious solution. However, *the size of the task involved in building a digital database should not be underestimated*. Most workers agree that more than 90 per cent of the effort in GIS-related studies is concerned with data capture (by digitising or other means), and co-registering data sets referenced in different map projections.

**Maps:** The hazard map is a convenient visual summary of information relating to the probability of landslides. It represents *one possible* interpretation of the data. A major

advantage of a GIS is that maps/plots can be created as required, designed to answer particular needs, using the latest available information held in the database. This is particularly important where the user is a non-geologist looking for practical solutions to particular problems.

**Data analysis:** The visual and statistical comparison of inter-relationships between different spatial variables held in the database allows the importance of various factors to be assessed in relation to landsliding. Thus, for example, the relationship between old landslides and a lithology or soil type, or perhaps a combination of soil type and slope class, can be judged using the GIS, and the results used to help understand, or perhaps 'model', the occurrence of landslide events in general. Such an approach is not new to geologists; traditionally, maps have been overlain on a light table to identify correspondences. The advantage of the GIS is that data sets may be more easily manipulated and viewed in combination, and quantitative measures of correlation derived to measure the results.

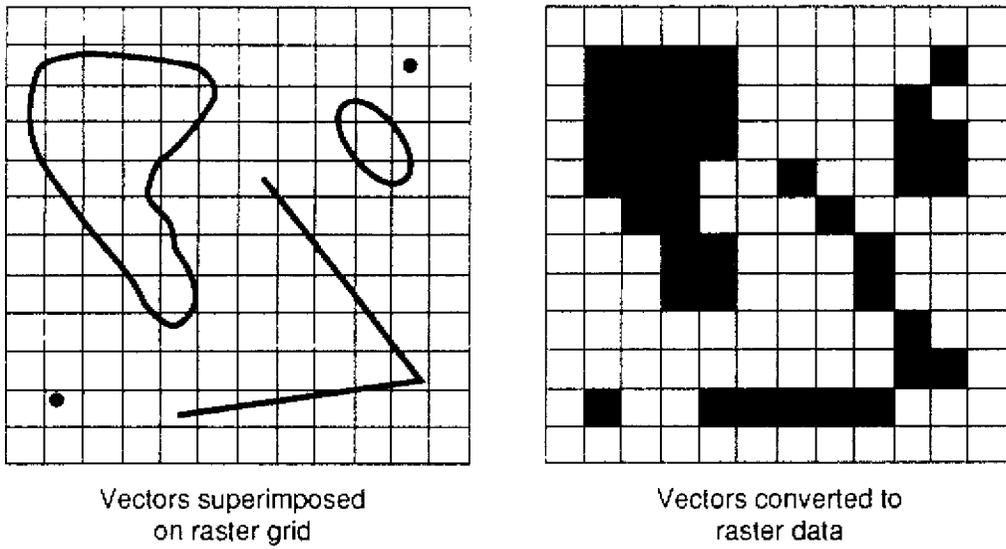
#### 4.2 GIS design and implementation

The large and growing range of commercially available GISs and the increasing awareness of this technology worldwide, indicate their value in environmental applications. The choice of GIS will depend on several factors, the main ones of which are: size/extent of problem; design requirements of the database; analysis needs; output formats; financial constraints; and, importantly, what computer/GIS systems are already in use and commercially supported nationally/locally. The last factor is in many respects the most fundamental as it will strongly influence the eventual choice. A community of users is important in regard to training and advice, data sharing, problem solving, and support/maintenance. None of these should be under-estimated. The choice of system may also be influenced by existing GISs within the organisation, or a need to share the eventual system with other users having different requirements. In Fiji, the GIS user community is already large and growing. Cooperation between individual organisations, such as through user groups, will lead to a sharing of data to the advantage of all.

Another important consideration is the complexity of the system chosen. The difference between a personal computer (PC) and a workstation is becoming increasingly blurred as processing power and data storage capability increase. Nevertheless, it is sensible to choose a system that is not over-sophisticated for the purpose. For example, in order to produce simple hazard maps, the output need not be cartographically very refined. Complex systems generally require considerable training and expertise, and consequently do not encourage sustained use. For some organisations, there is a danger of the system being so complex that only one specialist in the group can effectively operate it: should he leave, the system can easily fall into disuse.

The final basic consideration relates to the generic design of the system: vector or raster (Figure 4.1). In *vector* systems, map elements are represented by points, lines and polygons, the vertices of which are defined by map co-ordinate pairs. Each element may be associated with tabular attribute information describing its characteristics. Advantages of vector systems are that data storage requirements are small and the systems are well suited to cartographic plotting applications. Vector GISs are particularly useful for answering spatially-referenced database enquiries and for the analysis of networks such as drainage patterns. In the case of

### Vector vs. Raster Data



**Figure 4.1** Concepts of vector and raster representations of points, lines and polygons.

*raster* systems, the map area is divided into a mesh of grid cells (also called 'pixels') each of which records the value of the parameter. Raster data require more storage than vectors since every pixel must have a value, even if it is a code to indicate the absence of information. They also produce less elegant map output. Their main advantage is they are better suited to analyzing spatial relationships between parameters over continuous areas.

Given the range of considerations, there is usually no simple answer to the question: 'What is the best GIS system to use?'. The final choice is usually a compromise. In the present study various systems were used to develop a methodology. The choice was based on (1) immediate and long-term project requirements and (2) existing/potential hardware/software availability in the Mineral Resources Department and BGS. The following systems were employed:

- Intergraph Modular GIS Environment
- ILWIS
- IDRISI

#### **4.2.1 Intergraph Modular GIS Environment (MGE)**

MGE is a predominantly workstation-based system comprising various software modules which can be combined for different applications and which is underpinned by the MicroStation computer-aided drafting/mapping package. MicroStation is a sophisticated vector system for data capture, editing and presentation. Once digitized, map information can be passed into other modules for analysis and modelling. Of particular use to this study were the MGE Grid Analyst and Terrain Modeller modules. The former was used mainly to convert from vector to raster formats and the latter for the manipulation of DEMs.

The disadvantages of MGE are its complexity, cost and the limited capability for converting vector data to other proprietary vector formats for transfer to other systems.

#### **4.2.2 ILWIS ('Integrated Land & Water Information System')**

Of the systems used in this study, ILWIS probably comes closest to the definition of a GIS given above. It can manage and analyse raster and vector data in combination, and link to an internal DBMS for processing information in tables. Based on an upgraded PC with dual screen capability, one for graphics the other for textual information and control, this system represents an extremely cost-effective stand-alone solution for hazard mapping. ILWIS was the system originally chosen for the project but was largely replaced by IDRISI (section 4.2.3) because this latter system is likely to become more used in Fiji and the south west Pacific region.

ILWIS is capable of transferring data to and from many different systems, of digitizing vector information and of producing output maps to specified scales with annotation. Analysis of raster maps and tabular information is achieved by treating each data set as a variable in an equation easily entered by the operator in a calculator function.

### 4.2.3 IDRISI

IDRISI (Version 4.0) is a very low-cost raster-based GIS which can be installed on almost any PC. Although designed as a system to provide training in GIS technology, it can, nevertheless, perform operational tasks. It provides the same analysis functions as ILWIS albeit with a less elegant operator interface and some restrictions on parameters.

The main disadvantages of IDRISI are the very limited vector and map presentation capabilities and lack of a DBMS. To overcome these, it is recommended that additional software packages are installed on the system to provide these facilities. Another disadvantage is the limited ability to read information from other systems. For example, to load vector information captured using MicroStation, the file had first to be converted to the AutoCAD DXF format, read into ILWIS (thereby converting to its internal format), converted to Arc/Info GEN format and then read into IDRISI; a total of five different formats for the same information.

Although not currently used in the MRD, there are suggestions that SOPAC will provide and support the soon-to-be-released Windows-based version of the software.

### 4.3 Raster GIS analysis

The tools available in the raster GIS may be divided into four basic groups, described below.

**Database query:** This allows simple enquiries related to the stored information, such as *..show all areas with a slope angle greater than 30°...* or combined queries such as *.. show all areas with a slope angle greater than 30° that are underlain by Veisari Sandstone..* This is done by reclassifying each layer to show the presence or absence of a condition (known as a *Boolean* or *binary* image composed of 1s and 0s), and then logically overlaying the Boolean maps using the conditional operators *AND* *OR* to create a new display satisfying both criteria.

**Map algebra:** This allows a layer to be mathematically transformed, or several layers combined, using various scalar or algebraic operators. By this means, layers can be weighted and different situations modelled. The tools also allow the more complex mathematical overlay of layers using *ADD*, *SUBTRACT*, *MULTIPLY* & *DIVIDE*.

**Distance operators:** These allow a *buffer zone* (or 'corridor') to be calculated around a point, line or polygon where distance is an important aspect of the analysis (e.g. to test whether proximity to a fault/lineament is significant).

**Context operators:** The calculation of slope from a DEM is based on the relationship between the value at a point and neighbouring points. Other examples of context operators include digital filters which allow such operations as smoothing or shaded relief.

Analytical operations carried out on a GIS using the above tools fall into a few main categories. Database enquiries may be used to look for obvious spatial patterns in the data which allow ideas about relationships to be formulated. Thus, by examining in turn the spatial occurrence of landslides within different lithologies, one can decide whether lithology

is an important control on landslide occurrence. For example, the spatial association of landslide polygons with, say, volcanic breccia, might suggest that these rocks are prone to landslides, even though the precise explanation for this is not known. This can be done for all logical combinations of primary data layers. Secondary data layers may be derived from the primary information either by combining different layers or by transformation. For example, the digital elevation model may be used to generate secondary layers of slope and aspect which may be then used directly in the analysis.

#### 4.4 Fiji database

Mention has already been made of some of the information derived from the remote sensing data. These and other inputs are further described below. In assembling a GIS database derived from maps of differing ages and content, a major task involves converting the data sets to a common coordinate and map projection system. This is no trivial exercise, and considerable effort was expended in this study to achieve this. Various problems were encountered during data conversion, and these are briefly described below.

**Map base:** Fiji is in the process of converting from an older mapping co-ordinate system (Series X754, Edition 6-GSGS, published by the Ministry of Defence, United Kingdom 1972), to a new one based on the Fiji Metric Grid (FMG). The former 1:50 000 series maps were based on the Cassini-Soldner projection and Clark 1880 spheroid, with the projection origin at 18 degrees south, 178 degrees east, and a scale factor of 1.0000 at the origin. The coordinates of the origin are 5440.00 chains east, 7040.00 chains north (1 chain = 22 yards).

The new FMG is based on the Fiji Geodetic Datum 1986. Its definition is the same as the World Geodetic System Datum 1972, which is often referred to as WGS-72. The semi-major axis has  $A = 6378135.0$  m with a flattening  $F = 298.26$ . The FMG has a Transverse Mercator projection defined by the following parameters:

False Easting	2 000 000 m
False Northing	4 000 000 m
Central Meridian	178 degrees 45 minutes east
Central Scale Factor	0.99985
Origin	178 degrees 45 minutes east 17 degrees south

Problems in map data conversion: Some difficulties arose in digitising old format map information and converting it to the new projection system (e.g. geology, soils, coastline, river drainage). The coastline and drainage for old map sheet 19 (Mau) were digitised from the 1972 topographic map at the beginning of this study. The 1:50 000 topographic maps have the advantage of a UTM grid with one kilometre spacing superimposed over them, which allows the coordinates of any physiographic feature to be easily obtained. Unfortunately, the 1:50 000 geology (1967) and soil maps (1975) do not have a UTM grid, but instead a coarse latitude/longitude grid at 15 minute intervals (about 28 kilometres). This makes it difficult to obtain coordinates readings for features of interest. Before digitising, the equivalent FMG coordinates had to be obtained for the four map corners, together with some random points such as well defined physiographic features (e.g. river or road intersections).

To facilitate the digitising process, the Fiji-German Inventory Project (FGIP) at Colo-I-Suva provided BGS with calculated FMG map corner coordinates for the 1:50 000 Land Resource Division (LRD) forest inventory maps (produced in 1973 by the LRD of the ODA, UK). These maps appeared to be plotted on the same map base as the 1:50 000 geological maps. An official Cassini-to-FMG map coordinate conversion program was later (December 1993) obtained from the Fijian Land Information System Support Centre (FLIS) in Suva. This had been developed by the New Zealand Department of Survey and Land Information (September 1992). However, when the UTM coordinates of a road intersection near the top left corner of the old 1:50 000 topographic map sheet 20 (Suva) was converted to FMG coordinates using this program, its calculated position was found to be some 500 metres ENE of its location shown on the new 1:50 000 map sheet (FMS 31 O28 Nausori). Other locations tested gave similar errors.

If it is assumed that the computer program and new 1:50 000 maps are correct, this indicates that there is a serious problem with the absolute spatial latitude/longitude positions of physiographic information shown on the old 1972 topographic maps. This has important consequences when attempting to digitise information from these old maps and entering them into a GIS database.

Subsequently, the MRD provided BGS with a general purpose, PC-based, geodesy computer program developed by the FGIP (8 August 1994), called FMG.EXE. This converts geographical co-ordinates (expressed as decimal latitude and longitude) from the old map base to grid co-ordinates in the new FMG (and visa-versa). This program was compared with a coordinate transformation program available on the Erdas image processing system, using the four corner points for the old 1:50 000 topographic map sheets 17, 18, 19 and 20. Table 4.1 shows that the two programs give essentially the same sub-metre accuracy results. The Erdas program gives Easting values which are consistently about 0.5 metres greater than the Department of Forestry program. The Northing values agree to within 0.1 metre.

Another problem was that the geology maps appear to have incorrectly-labelled latitudes, the values being 12 seconds of arc too large. This can be seen by overlaying the geology (1967) and topographic maps (1972) and matching physiographic features. This procedure demonstrates that these two map bases have the same actual corner points. Thus, the southern boundary of geological map sheets 17 and 18 should be  $18^{\circ} 17' 48''\text{S}$  (not  $18^{\circ} 18'$ ) and the northern boundary  $18^{\circ} 02' 48''\text{S}$  (not  $18^{\circ} 03'$ ). Similarly, the southern boundary for geological map sheets 19 and 20 should be  $18^{\circ} 14' 48''\text{S}$  (not  $18^{\circ} 15'$ ) and their northern boundary  $17^{\circ} 59' 48''\text{S}$  (not  $18^{\circ} 00'$ ).

However, even after allowing for the 12 second shift in latitude, digitising the old topographical and geological maps using the corner points, calculated either by Erdas or the latest computer program [FMG.EXE] (see Table 4.1), still produces a significant mis-registration between physiographic features when compared with their positions on the new 1:50 000 topographic maps (1993). For example, two river confluences from sheet 18 gave an ESE shift of about 400 m west and between 90 and 220 m south as shown on the new map M29 Korolevu. Other points gave differing shifts.

*It was therefore not possible to directly transform data points analytically from the old map projection to the new one.*

Table 4.1 Comparison of 1:50 000 geology map sheet corners in latitude/longitude & computer calculated Fiji Metric Grid coordinates

1:50 000 SHEET	CORNER	GEOLOGY MAP LATITUDE °S	GEOLOGY MAP LONGITUDE °E	DECIMAL LATITUDE °S	DECIMAL LONGITUDE °E	ERDAS CALCd FMG EASTINGS	ERDAS CALCd FMG NORTHINGS	FMG.EXE CALCd FMG EASTINGS	FMG.EXE CALCd FMG NORTHINGS
17	SW	18° 17' 48"	177° 40' 00"	18.296666667	177.6666667	1885475.22 E	3856171.13 N	1885474.68 E	3856171.17 N
	NW	18° 02' 48"	177° 40' 00"	18.046666667	177.6666667	1885312.04 E	3883841.57 N	1885311.30 E	3883841.61 N
	NE	18° 02' 48"	177° 55' 00"	18.046666667	177.9166667	1911780.36 E	3883978.73 N	1911779.82 E	3883978.77 N
	SE	18° 17' 48"	177° 55' 00"	18.296666667	177.9166667	1911905.88 E	3856309.93 N	1911905.34 E	3856309.97 N
18	SW	18° 17' 48"	177° 55' 00"	18.296666667	179.9166667	1911905.88 E	3856309.93 N	1911905.33 E	3856309.97 N
	NW	18° 02' 48"	177° 55' 00"	18.046666667	177.9166667	1911780.36 E	3883978.73 N	1911779.82 E	3883978.77 N
	NE	18° 02' 48"	178° 10' 00"	18.046666667	178.1666667	1938247.32 E	3884080.10 N	1938246.78 E	3884080.15 N
	SE	18° 17' 48"	178° 10' 00"	18.296666667	178.1666667	1938335.17 E	3856412.51 N	1938334.63 E	3856412.55 N
19	SW	18° 14' 48"	178° 10' 00"	18.246666667	178.1666667	1938317.51 E	3861946.21 N	1938316.97 E	3861946.13 N
	NW	17° 59' 48"	178° 10' 00"	17.996666667	178.1666667	1938229.89 E	3889613.66 N	1938229.35 E	3889613.58 N
	NE	17° 59' 48"	178° 25' 00"	17.996666667	178.4166667	1964703.36 E	3889679.09 N	1964702.82 E	3889679.01 N
	SE	18° 14' 48"	178° 25' 00"	18.246666667	178.4166667	1964753.42 E	3862012.42 N	1964752.89 E	3862012.34 N
20	SW	18° 14' 48"	178° 25' 00"	18.246666667	178.4166667	1964753.42 E	3862012.42 N	1964752.89 E	3862012.34 N
	NW	17° 59' 48"	178° 25' 00"	17.996666667	178.4166667	1964703.36 E	3889679.09 N	1964702.82 E	3889679.01 N
	NE	17° 59' 48"	178° 43' 00"	17.996666667	178.7166667	1996469.54 E	3889710.50 N	1996470.30 E	3889710.42 N
	SE	18° 14' 48"	178° 43' 00"	18.246666667	178.7166667	1996474.55 E	3862044.21 N	1996475.30 E	3862044.12 N

In order to overcome these problems, it was assumed that the old maps were incorrect. The digitised map data were transformed by a least squares adjustment to the FMG using Intergraph Projection Manager software. Even after this transformation, it was discovered that the raster GIS files supplied by the FGIP needed a shift in origin to achieve full registration. This was achieved on the GIS.

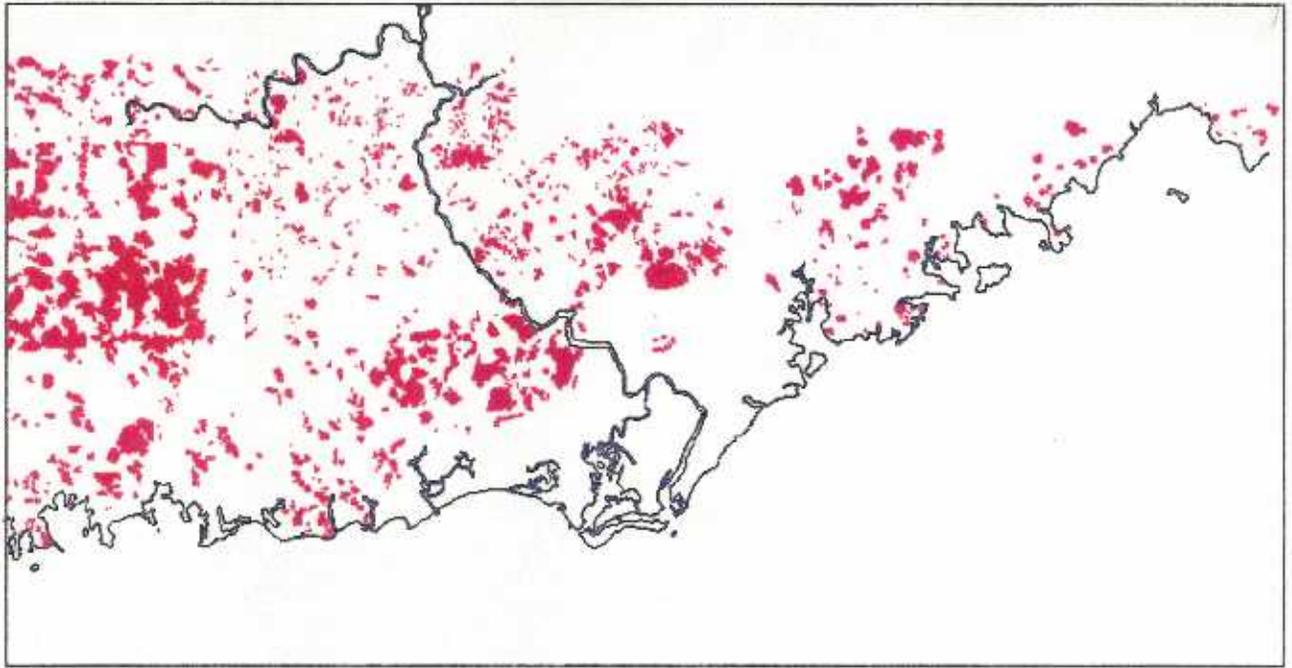
**Landslides:** The classification of photointerpreted landslides was described in Section 3.3.2. The 'old', 'transitional' and 'fresh' landslide categories were separately digitised. The old and transitional types were digitised as filled polygons. However, many of the fresh landslides are narrow and often sinuous gully run-outs, which were difficult to digitise directly as polygons. During interpretation, all were marked with a point representing the nominal 'initiation point' near to the top of the backscarp. The fresh landslides were finally digitised in several ways: as a point (where very small), as a point plus a line to the toe (where narrow/sinuuous), or as a point plus polygon (where sufficiently large). During GIS processing, polygons were created of all the 'points' and 'points-plus-lines' sub-categories by generating a narrow 1-pixel wide buffer around them. Finally, all fresh landslides were merged into a single category in which every slide was represented by both a polygon and an initiation point. Figures 4.2 to 4.5 show the distribution of old, transitional, young and total landslide polygons, respectively.

**Lineaments:** Lineaments related to drainage and topography were interpreted by some investigators only. As this was not a consistent nor complete data set across the study area, and due to lack of time, it was not digitised.

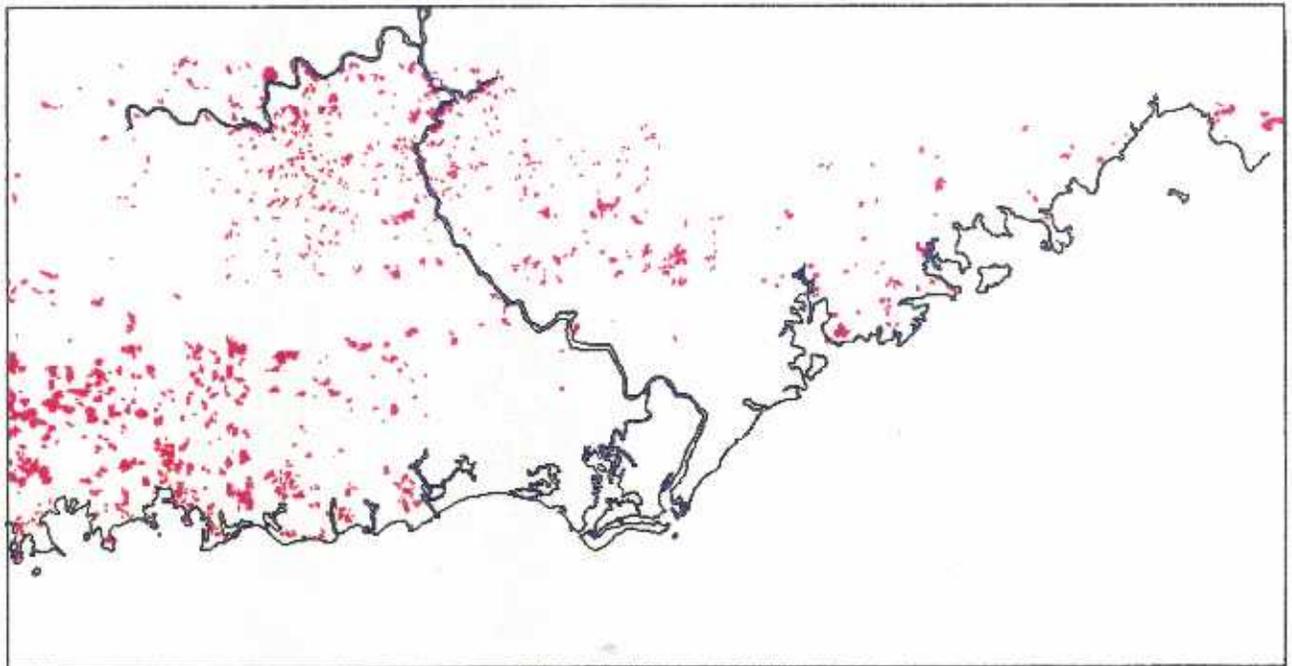
**Geology:** The geological boundaries were digitised from the published 1:50 000 scale geological maps. These sheets are essentially large-scale reconnaissance maps and show some edge-match discrepancies. These differences were arbitrarily reconciled prior to digitising. Although it is likely that lithological-structural differences affect/control landslides, the present maps may not contain enough underlying lithostratigraphical information to allow significant conclusions to be drawn. A plot of the digitised geology map is shown in Figure 4.6.

**Topography:** A digital elevation model was provided by the FGIP based on the digitised old series 1:50 000 topographic sheets. It is understood that this information was scanned and converted to digital files from which a digital elevation model (DEM) was produced. The DEM was in turn used in the study to generate slope angle maps (in 5° classes) and slope aspect maps (in 8 sectors). The details of this work are described separately in Section 4.4. The elevation, slope angle and slope aspect maps are shown in Figures 4.7, 4.8 and 4.9 respectively.

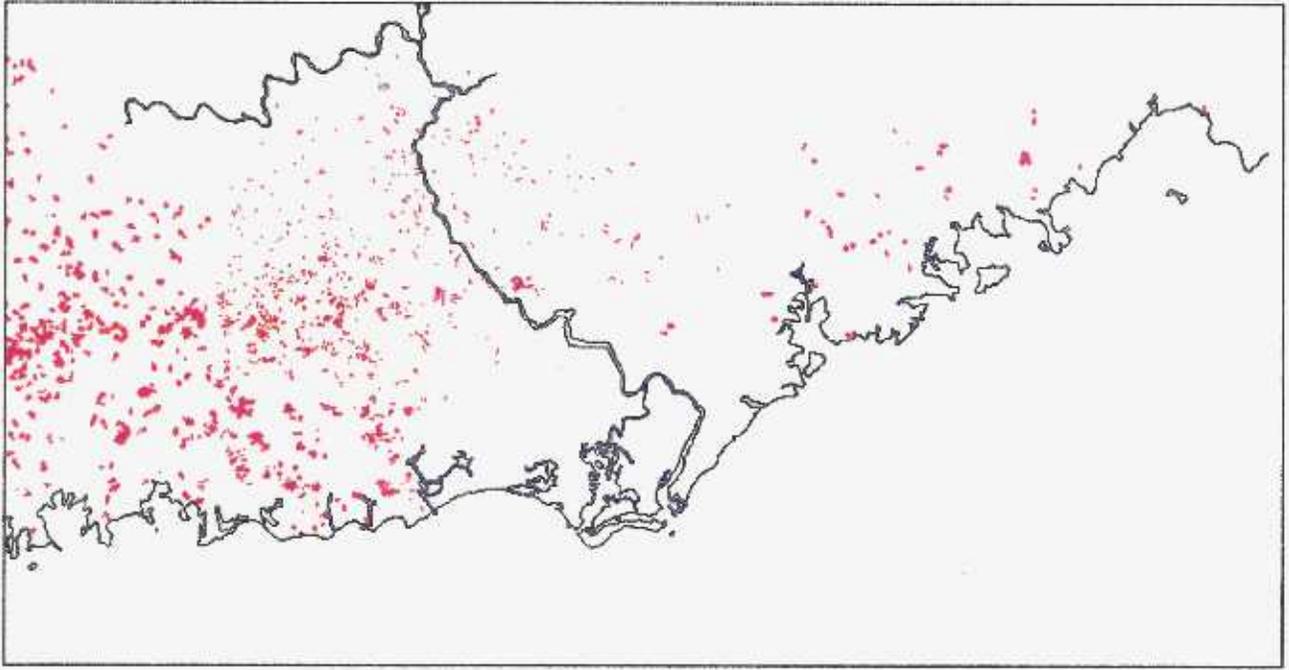
**Soils:** The pedological soil scheme used in this study is a modified version of the classification developed by the Ministry of Primary Industries (MPI) which represents an adaptation of the original Twyford and Wright (1965) classification (section 2.3.1). The soil types in the MPI scheme, based largely on parental lithological associations and geographic domains, were simplified into five groupings for description purposes. However, in order to test the wider variability of pedological soils against other data sets, 43 classes were digitised for GIS analysis. The soils distribution map is shown in Figure 4.10.



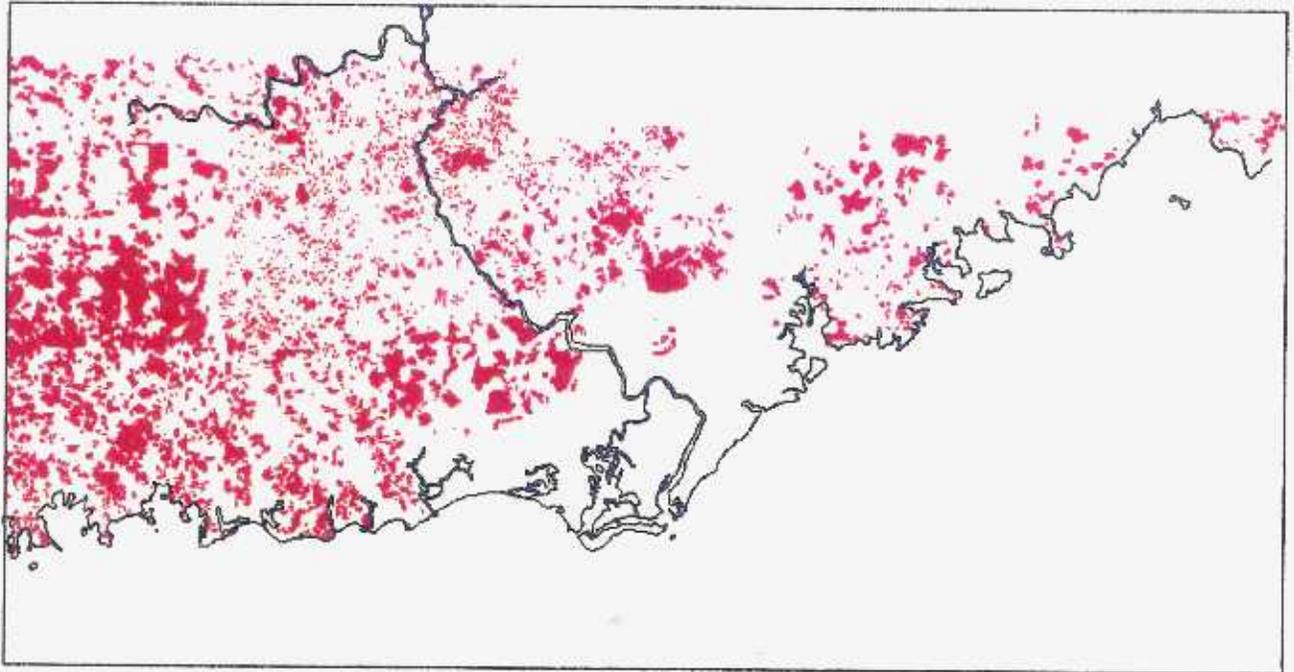
**Figure 4.2** 'Old' landslides interpreted from aerial photographs.



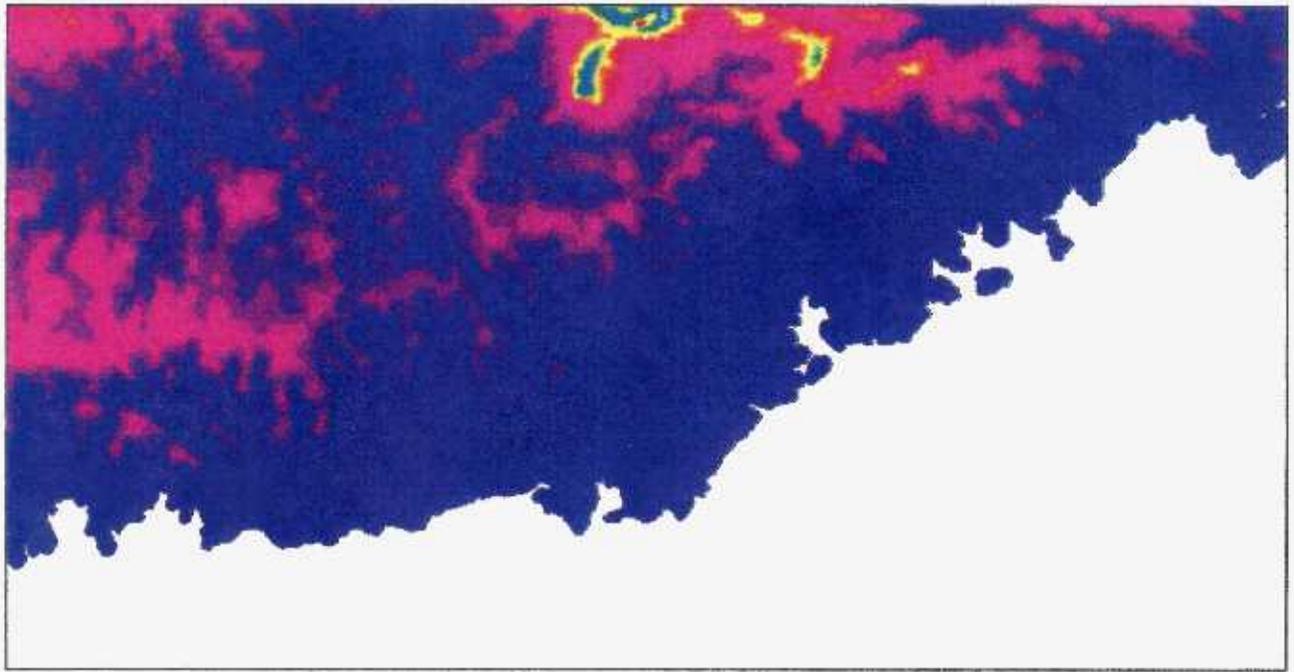
**Figure 4.3** 'Transitional' landslides interpreted from aerial photographs.



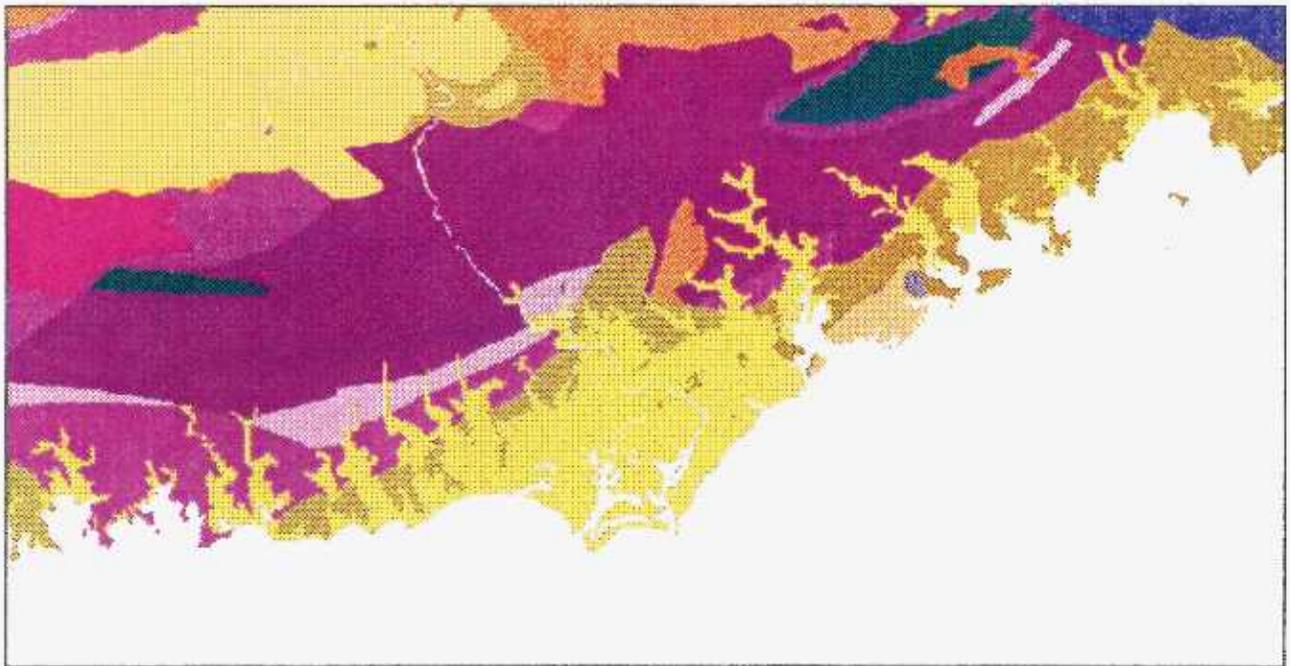
**Figure 4.4** 'Young' landslides interpreted from aerial photographs.



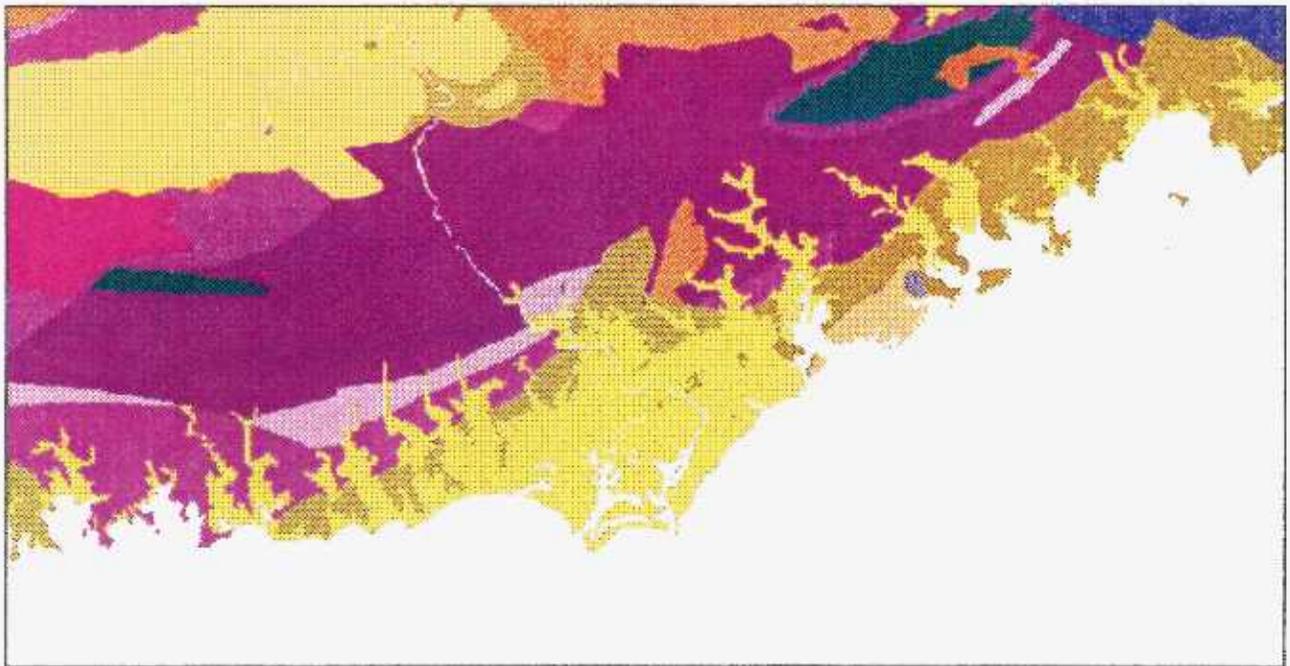
**Figure 4.5** Total landslides ('old' + 'transitional' + 'young').



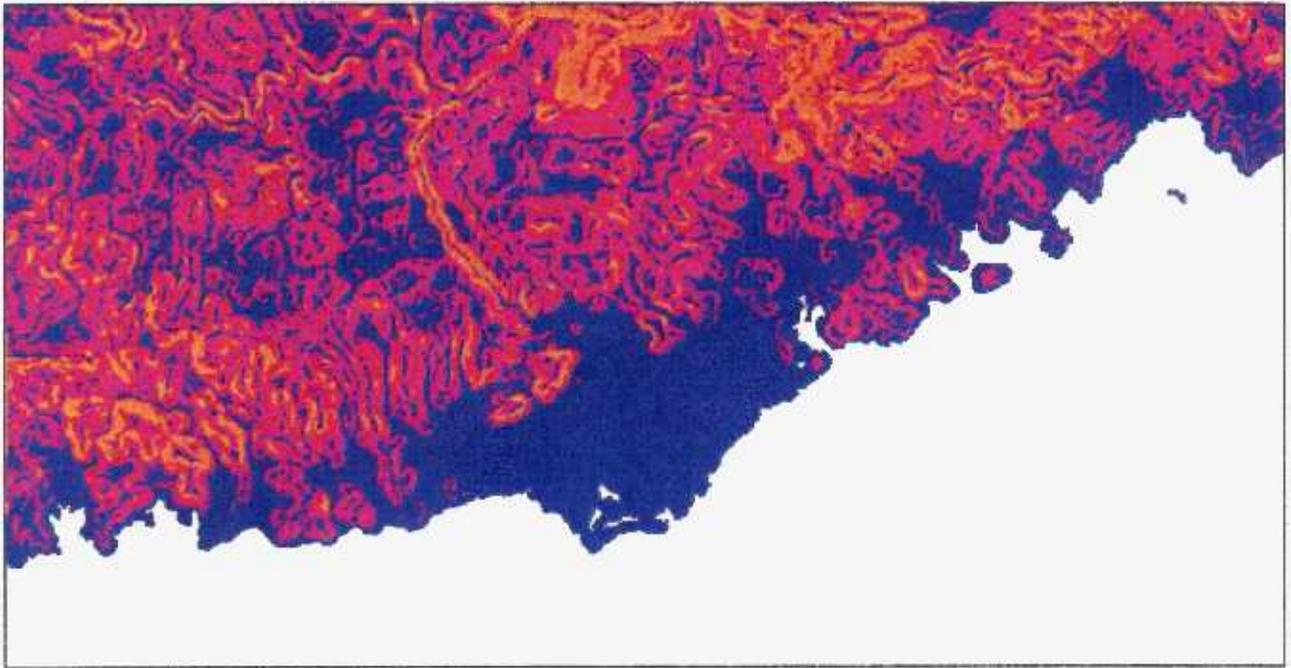
**Figure 4.7** Digital elevation model (DEM) for south east Viti Levu (17 classes of 50 m, range sea level to 850 m).



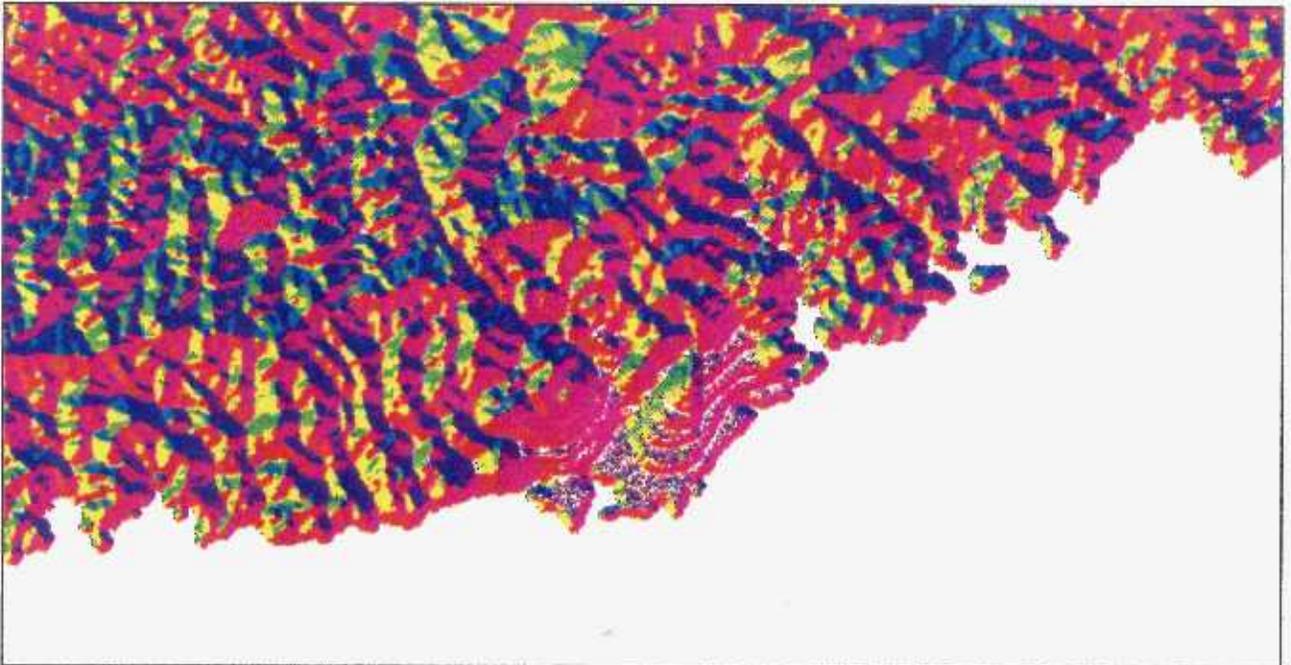
**Figure 4.6** Geology of south east Viti Levu (compiled from published 1:50,000 scale maps).



**Figure 4.6** Geology of south east Viti Levu (compiled from published 1:50,000 scale maps).



**Figure 4.8** Slope angle map for south east Viti Levu (equal area plot based on 5° slope angle classes).



**Figure 4.9** Slope aspect map for south east Viti Levu (8 sectors).