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GEOSCIENTIFIC DATABASES AND RELATED COASTAL ZONE MANAGEMENT ISSUES

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Stilt village, southern shore of Labuan Island, Malaysia

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EXECUTIVE SUMMARY

The root causes of environmental problems in the Asia region are poverty, the lack of development, and environmentally unsound development (Jalil, 1993). Rau (1994) outlined the need for geoscientific data to assess man-made urban and coastal ecosystems in east and southeast Asia. Rau argues that the geological conditions in these areas need to be understood prior to development, though this rarely happens, and that geoscience is an important part of Coastal Zone Management (CZM). In 1992, CCOP, a regional intergovernmental organization for the Co-ordination of Coastal and Offshore Geoscience Programmes in East Asia set up *COASTPLAN*, to be funded largely by the Netherlands Government, and to investigate coastal zone problems in the area. The British Geological Survey was funded in 1993 on a three year programme by the ODA Technology Development and Research programme to assist with the establishment of geoscience databases within *COASTPLAN.*

After discussions with CCOP the project was set up with the co-operation of the Geological Survey of Malaysia (GSM) whose Marine Geology Group was carrying out extensive work on and around the island of Labuan, Eastern Malaysia. GSM has assisted the project both with data, logistic support and financial assistance for the authors whilst in Malaysia.

The project is divided into three: the digital database, a case study on Labuan, and an assessment of the uses of remote sensing to CZM, in conjunction with the other data sources.

The database set up follows well established procedures used by the British Geological Survey. A series of tables were drawn up and finalised after discussion with GSM staff. These tables covered a range of sample, seismic, and geochemical data. The database was set up on PCORACLE but can be used with other similar software. The database is now operational within the Marine Geology Group of GSM and was demonstrated to other geological surveys from the region at a *COASTPLAN* workshop held in the Philippines in early 1996. CCOP and GSM aim to assist other organisations wishing to use the database.

If the organisations attending this workshop are to move into digital cartography and GIS then they must collect their data in a standard format, reformat existing information into this format, and keep updating the database. They must also appreciate that maintaining the database is more demanding of time and effort than setting it up.

The case study involved a visit to the coast of Labuan in early 1994 to examine the morphology and sedimentology of the coastal zone, and an evaluation of reports and air photographs at GSM in Ipoh. The results showed erosion and accretion of coastal sectors on the eastern and western coasts of the island while the southern coast was in near equilibrium. Sediment transport was generally from northeast to south west under the influence of the Northeasterly Monsoon. Major construction along the coast should be considered with care for there is likely to be an implication to the sedimentological regime down drift.

The remote sensing Landsat image provided by GSM allowed an evaluation of the Sabah coast adjacent to Labuan. Teluk Kimanis northeast of the Klias peninsula was dominated by barrier ridges whilst the coast facing Brunei Bay is a slowly accreting low energy-delta onto which most of the alluvial sediments accumulate. Classification of the Landsat scene was found to be a powerful method of rapidly mapping remote coastal environments and ecology.

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GENERAL INTRODUCTION

The root causes of environmental problems in the Asia region are poverty, the lack of development, and environmentally unsound development (Jalil, 1993). These problems are being addressed by many non-governmental organisations and one approach has been to promote programmes to protect, or enhance the environments under threat (Jalil, 1993). Most of the major urban centres of the region are located in coastal environments and the understanding of these environments is becoming increasingly important in planning their development.

Rau (1994) outlined the need for geoscientific data to assess man-made urban and coastal ecosystems in east and southeast Asia. He argues that the geological conditions in these areas need to be understood prior to development, though this rarely happens, and that geoscience is an important part of Coastal Zone Management (CZM). Both Rau (1994) and Jalil (1993) described the role that non-governmental organisations have played in improving geoscientific understanding of the environments under development, or under threat, across the region.

CCOP, a regional intergovernmental organization for the Co-ordination of Coastal and Offshore Geoscience Programmes in East Asia, has for over twenty-five years assisted the search for offshore minerals in southeast and east Asia by co-ordinating the skills of the Co-operating Countries with the needs of the Member Countries. In 1990 CCOP changed the thrust of its work to include the investigation of geoscience in the coastal zone. In the same year CCOP hosted a conference in Chang Mai, Thailand, on the theme of *Global Environmental Change - the role of the geoscientist.* A major recommendation from this meeting was for CCOP to develop a programme for the coastal zone which would be termed *COASTPLAN.* The Government of the Netherlands, through Rijks Geologische Dienst (RGD), agreed to organise the programme and in September 1992 a meeting was called by RGD in Haarlem, of CCOP Co-operating and Member Countries. From these discussions the CCOP Technical Secretariat prepared the *COASTPLAN* proposal, which was entitled "Geosciences for integrated resources management and development of southeast and east Asian coastal zones".

The *COASTPLAN* proposal is funded by the CCOP Co-operating Countries with the Netherlands Government providing a substantial proportion of the total. The programme is divided into three parts: seminars in southeast and east Asia by experts in Coastal Zone Management from the Co-operating Countries to demonstrate how the subject is being approached in these countries; the placement of an expert in coastal zone geoscience in the CCOP Technical Secretariat; and a study of one or more coastal areas from the region to demonstrate to CCOP Member Countries modern techniques in Coastal Zone Management. The *COASTPLAN* programme commenced in June 1995 when Dr L van der Valk of RGD joined the CCOP Technical Secretariat in Bangkok.

Following the 1992 Haarlem meeting, BGS approached the UK Overseas Development Administration (ODA) for funds from its Technology Development and Research Programme(TDR) to enable the design and development of geoscientific databases within the overall *COASTPLAN* project. Geoscientific data from the coastal zone of the region was accumulating rapidly, but in many countries was not being collected into a coherent database. Without such a database information was in danger of being lost, or certainly not being easily available, and it would not be possible in future to move the information into a geographic information system (GIS).

TDR project was approved by ODA and commenced in April 1993 as a contribution to the UK government programme to aid technical assistance to developing countries. The BGS project moved in advance of the *COASTPLAN* programme. As the site of the *COASTPLAN* studies remained undecided, BGS decided in November 1993 to commence the studies centred on the island of Labuan, Malaysia. This location was chosen as data were available from island following extensive coastal studies of the island by the Jabatan Penyiasatan Kajibumi Malaysia (Geological Survey of Malaysia - GSM), and their expanding general interest in marine and coastal geology.

The programme has been a co-operative venture between BGS and GSM. GSM have provided both logistical and financial assistance, and the data used to carry out the programme. The joint programme was divided into three parts. Part 1 describes the development of a computerised database for coastal and offshore geoscientific data. Part 2 is a case study of the coastal geology of Labuan incorporating data which could be stored in the database. Part 3 is an assessment of remote sensing data from Labuan and its surrounds which could also be incorporated with data from the database.

This report is intended to provide geologists of the region with an insight into some approaches which benefit coastal zone management. The section on computerised database both sets out the rationale behind the a coastal geoscientific database, and describes the tables set up for GSM. The case study of Labuan is an evaluation of field data, largely supplied by GSM, related to hydrodynamic processes which affect the modern coast of the island.
The remote sensing investigation examined a Landsat image of Labuan and the surrounding region (provided by GSM), with the aim of assessing the usefulness of this type of data in coastal zone management and its potential for use in a future geographic information systems (GIS) of the coastal zone.

Relevance of geoscientific databases to coastal zone management

Coastal zone management embraces a range of disciplines and interests including planning, fisheries, tourism, coastal defence and economic resources. Much of the information of interest is common to all of these themes. There is an advantage for certain organisations to accumulate specific data sets, and, with the advent of relational databases, making these widely available. Such databases should be set up with a long-term aim, measured in decades rather than years, and care should be taken to ensure that the scheme adopted has the flexibility and long-term support to satisfy this requirement.

This project examines some aspects of geoscience relevant to coastal zone management. The range of potentially useful information is wide but amongst the more important may be sample and borehole information with lithological, mineralogical and geochemical data, and geophysical information including seismic reflection profiling, bathymetric, and gravity data. The project set out to design a flexible relational database which could be expanded at a later date to take an additional range of data, or link with other databases.

It is pertinent to examine the experience of the United Kingdom before turning to southeast

Asia and in particular Malaysia. Since 1992 central government in the United Kingdom has encouraged local authorities to produce *Shoreline Management Plans* which cover specific coastal cells or sub-cells. A coastal cell being a length of coast where the littoral processes are inter-dependant. A report on earth science information for the coastal zone (DoE, 1995) was funded by central government to assist in the preparation of such plans. The first drafts of the *Shoreline Management Plans* are now complete and they clearly identify the role of geoscience in coastal zone management.

In the United Kingdom the most extensive database on coastal geology is that held by the British Geological Survey. This includes the onshore land mapping which started in 1835, and the results from over 140 000 onshore boreholes, and the geochemical and geophysical surveys. Offshore data held includes results from over 550 shallow boreholes, 35 000 sea bed samples and shallow cores, and about 500 000 line kilometres of geophysical profiling. Much of this data are held on an Oracle relational database which was set up over 10 years ago. The database is continually updated and used by a wide range of geologists within and outside BGS.

The main aim of this project was to set out the basic principles for a similar database and establish a working example in the GSM which could be copied by CCOP Member Countries with a specific interest in coastal and marine geology. In 1991 the Marine Geology Group of the Geological Survey of Malaysia embarked on a major coastal data collection exercise and quickly appreciated the need for a database in which to store the information.

The background to Malaysian interest in coastal management issues was reviewed by Yunus (1991). Notable amongst these programmes were :

- detailed mapping of the Quaternary geology of the coastal zone since 1976
- the Economic Planning Unit's National Coastal Erosion Study in 1985
- the work of the Malaysian Wetlands Working Group
- the work on sea level change in Malaysia led by Prof. Tija

Work to prepare coastal management plans for Malaysia began in South Johore where an Integrated Resource Management Plan was set up in the late 1980's ((Ch,ng, 1989). This work led from an ASEAN-US initiative and included 25 state and federal agencies. It recognised the need for economic evaluation of the land use in the coastal zone and the need for a multispectral approach. In addition the Coastal and Offshore Institute (COEI) has been established at the Universiti Teknologi Malaysia (UTM) has a wide range of interests in this field.

The Marine Geology Group in GSM identified early in their data collection the need for a relational database to store their new and future data. This project addressed this need and provides an approach which may be followed by other similar organisation from the region.

PART 1 - DATABASE DESIGN AND IMPLEMENTATION

1.1 INTRODUCTION

In the past few years the geological surveys of many countries in east and southeast Asia have started to collect considerable volumes of information on the geology of their continental shelves and coastal zones. These data are expensive to collect and may be important in providing baseline values to measure future changes in the environment. Similar offshore information may already exist within the hydrocarbon industries operating across these waters, on the hydrographic charts from the same waters, and from scientific studies carried out by other national or international organisations. Usually this range of data is not collected or stored in an uniform format, and is seldom collated into a single database. While only geoscientific data are considered in this report, oceanographic and biological data could be incorporated into a similar database.

Presently most of the geological surveys collect data on a local basis, and many have no country-wide system for storing existing and newly acquired geoscientific information. In most cases the volume of existing data is not excessive and could be integrated easily into a computerised database. However, unless the implementation of a database is embarked upon soon, and given high priority, it will become increasingly difficult for CCOP Member countries to set up a comprehensive geoscientific database of their coastal zone and continental shelf.

The requirement is for a database which can store the existing range of geoscientific information, which has scope for expansion, which is globally supported, and from which maps may be generated. Another requirement is that the data are held in a format which can feed into a Geographical Information System (GIS) such as ARCInfo. There is no possibility of a GIS being set up without the data being organised first into a comprehensive database.

The BGS use an ORACLE database which has been linked to ARCInfo, Intergraph and MapInfo GIS'. As the Geological Survey of Malaysia (GSM) has ORACLE and ARCInfo it was decided to prepare the database for the project on PCORACLE for compatibility with existing systems and expected future developments. Although PCORACLE is more complex than that necessary for completion of this project, it is the system likely to be adopted as the GSM-wide database, and this project helped to establish a survey-wide standardisation. For other geological surveys the adopted database should be that common to the organisation. If no such standard approach exists then the solution adopted here may be applicable.

What cannot be stressed strongly enough is that data from all disciplines available for a particular topic should be input to the database. This only comes about after the establishment of a system accepted by all working in the organisation. The process of inputting existing data, and the constant updating of the database with new data is time consuming but without this effort the database will be of limited value. The laborious process of data entry is common to all databases of this type, and cannot be avoided if the end product is to include most of the available data. Validation and checking of data put onto the database must also be thorough.

The *coastal zone* in this report is taken in its broadest sense to include a country's offshore waters and adjacent land areas. The creation of a database covering a set distance landward and seaward from the coastline merely represents a subset of the larger dataset.

The range of information which may be incorporated into a geoscientific database is almost infinite, but in this report the aim has been to include a range of specific data and to provide the facilities for future expansion by Member Countries.

1.2 THE BGS DATABASE

1.2.1 Background

British Geological Survey has been collecting onshore data for over 150 years and offshore data for over 25 years. A computerised database of offshore information was set up in the 1970s (Fyfe and Mould 1987). This continued to be expanded through 1980s and in 1986 it was transferred on to a VAX8600 using an ORACLE data management system. During 1995 the majority of ORACLE databases were moved to UNIX SUN Servers, this process will be completed in early 1996 when the VAX is decommissioned. The new system enables users to access their databases via their own PC utilising the ORACLE Tools or ACCESS software. All Groups in BGS now hold data in ORACLE though compatibility between all the BGS data has not been achieved.

The BGS onshore borehole database was built to maintain borehole data for the UK in a standard and consistent format. The system was developed and implemented in ORACLE on a VMS VAX server in order that the data could be held in a powerful relational database and be accessible to a large number of staff (Giles, 1991). Approximately 90 members of staff in England, Scotland and Wales may retrieve data from the borehole database. Data inputting is strictly managed, all data is entered into temporary tables then validated by a geologist before the database manager allows entry to the permanent tables. Although many staff have access to extract data they generally rely on a small number of SQL (Structured Query Language) or SQL*Plus experts.

This database has been designed such that the information it holds may be retrieved in a range of combinations to suit differing user requirements, using SQL*Plus. For example, locational information may be required for boreholes within a project area, or all boreholes for the project which prove a particular lithostratigraphical unit, or all boreholes drilled after 1950 to a depth of 100 m or more. Creation and maintenance of the onshore database has provided a versatile and consistent source of information for BGS field mapping projects and commercial contracts.

The BGS offshore database contains information on some 30 000 sample stations and over 500 000 km of seismic profiling. Information on the geochemistry, geotechnical properties and sedimentological properties of the samples are kept along with information on hydrocarbon boreholes (Alexander and Richardson, 1991). In addition gravity and aeromagnetic data are held for the offshore areas.

Before information can be put into a database there needs to be a careful assessment of the type and range of data to be collected and the time over which the database will be operating. In the case of the UK offshore waters this decision was made in about 1970 when a scheme was devised for numbering the samples and recording the geophysical data. When the scheme was set up it was appreciated that it would be at least 20 years before all the area was covered. Preparation of the format of the proposed database therefore needs an appreciation of the long term perspective.

1.2.2 Application

Presently many of the geological surveys in east and southeast Asia hold some of their information on databases, however, they may not be in a format that can be expanded over a long time scale and may not be able to carry a wide range of data. It is therefore important to put in place a database which can carry the requirements of the organisation over a long term and which will not require significant changes to accommodate new technology.

The aim of this project is to devise a database which will cover the geoscientific requirements in the coastal zone and across the territorial waters of the country. Presently the organizations working on the geology of these areas are focusing on limited areas but with time data from all the territorial waters will be put into a database. Figures 1a and 1b show the extent of Malaysian territorial waters which locally extend for over 200 km offshore.

The problem of producing maps from the database is also addressed though on a more general basis using the experience of the BGS over the past 20 years to advise those wishing to extract data from the database. Again the aim is to examine both the short and long term needs of the geological surveys, and not simply that which would satisfy the immediate need.

BGS use an in-house program ALLPLOT and the Microstation mapping software to produce maps from the ORACLE offshore database on a variety of plotters. As the ALLPLOT program is written in FORTRAN on the VAX it is not easily transferable onto PC systems. The solutions adopted for this project are to use the Atlas Mapmaker program to produce basic maps and Microstation for the more complex maps. Alternative solutions, expanded upon below are to use ARCInfo, GEOSoft or HYDRO survey software as the main plotting systems.

1.3 THE PC ORACLE DATABASE

The database described below is a simplified version of the BGS onshore and offshore ORACLE database. It has been simplified merely to allow this programme to be completed on time. Once this prototype is functioning smoothly then there should be few problems in expanding it to include the wider range of facilities of the larger BGS database.

1.3.1 Software

The database adopted for this project was PCORACLE Version 7.

The use of an ORACLE database utilises the benefit of existing BGS expertise in the building and use of ORACLE databases. ORACLE 7 is usually mounted on a server (UNIX in the case of BGS) and accessed from a PC through DOS or Windows environments, via the SQL*Plus query language. Data entry forms are accessed through Windows and provide an input format to mirror the paper forms used to record data collection. ORACLE 7 may

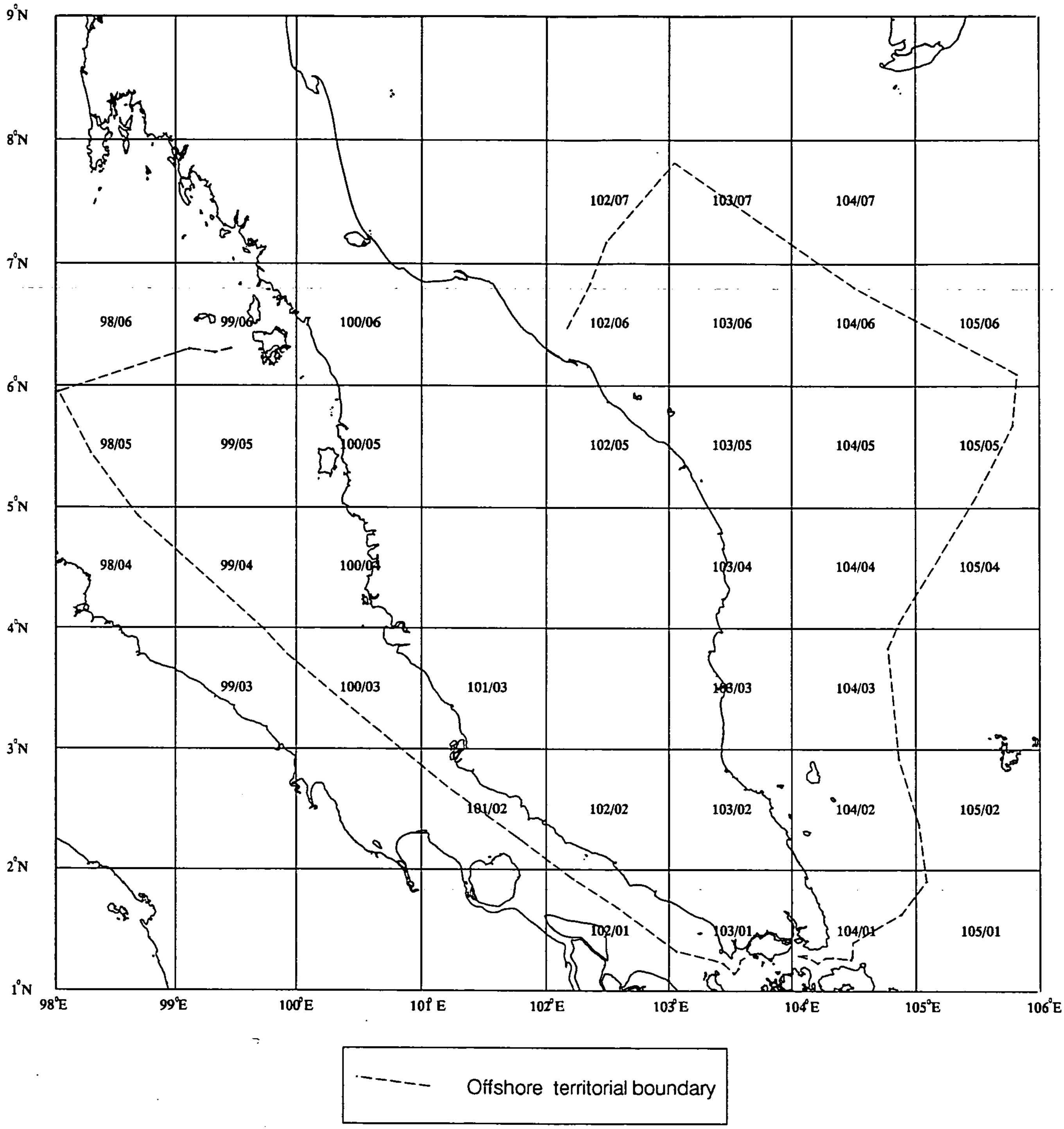


FIGURE 1a. Degree rectangles for Western Malaysian territorial waters

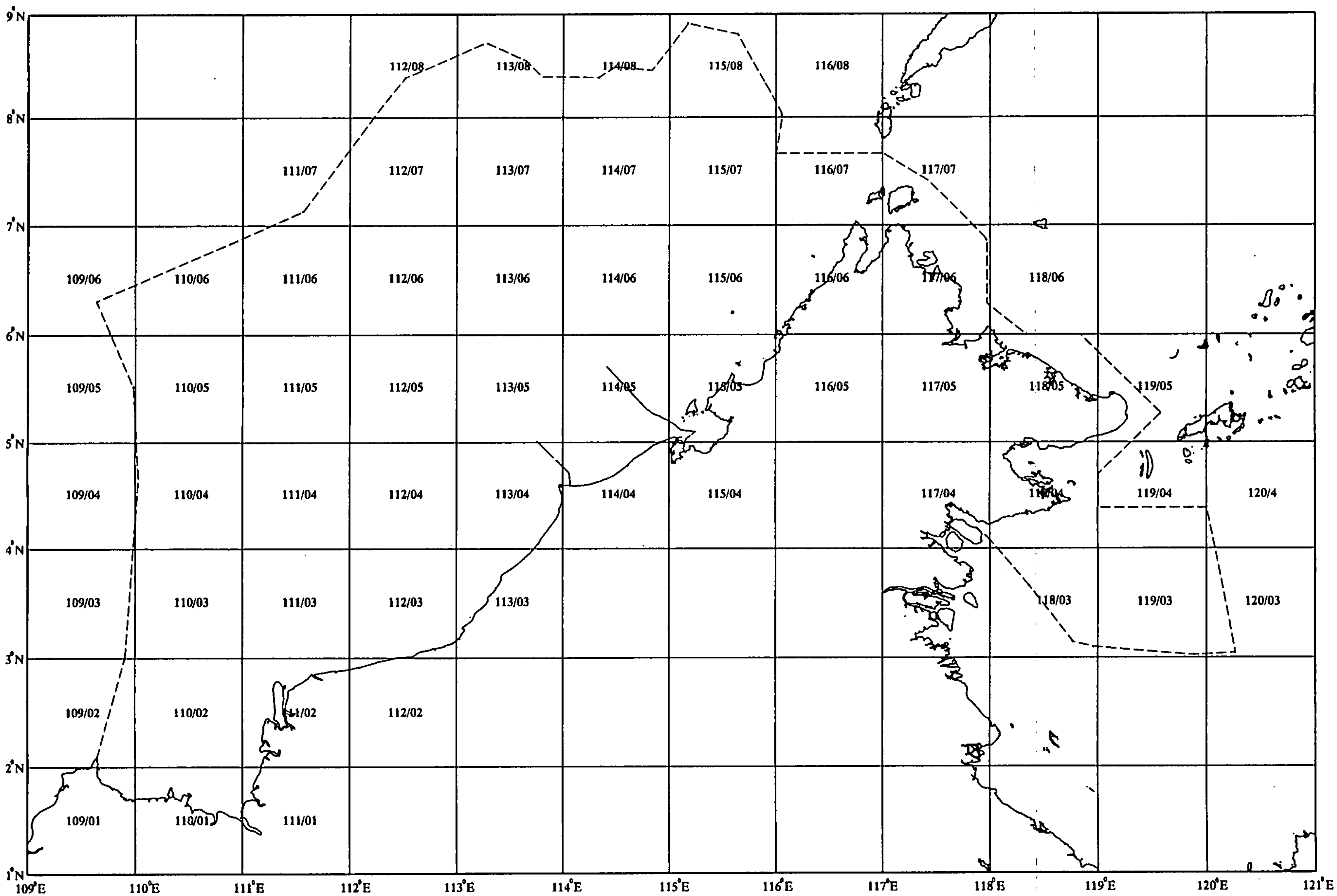


FIGURE 1b. Degree rectangles for Eastern Malaysian territorial waters

operate with single or multiple user access.

Originally it was envisaged that the GSM database would be a stand-alone system with no other demands on space, using the ORACLE 6 software. However, during the first few months of the project it was decided to run the database on a server across a Novell LAN (Local Area Network) to be accessed from one or more PCs, giving greater flexibility in the future. ORACLE 7 is designed to work with multiple user access and network connections. The security of the database would have to be more stringently designed to cope with this.

To access ORACLE effectively on a PC the computer should have 8 mb or preferably 16 mb of RAM and a 400 mb hard disk. Tools software may be run from the server or mounted on an individual's PC, enabling requirements to be adapted to a user's preferences. To interrogate the database a user must have one or more of SQL*Plus, SQL*Forms or third-party software such as ACCESS.

Autoexec.bat and Config.sys files for the PC, which define a PC's configuration, need to be setup to run both mapping and database software. ORACLE can be password protected to prevent unauthorised entry into the system.

1.3.2 Establishing data standards

Before database tables are designed a standardisation of the data classifications to be used must be put in place. The possibility of holding non-compatible data sets in the database is then reduced. This is especially important when establishing formats for unique identifiers (primary keys, explained in detail in 1.3.3), scientific names and measurements.

Offshore geophysical and sample data have been recorded in digital and analogue formats in Malaysian waters, organised for specific projects rather than within a national collection. It was necessary to establish procedures whereby this information could be converted to a format suitable for input into a geoscientific computer database. After discussions with GSM staff, it was decided to follow the British system of numerical registration for data based on their geographical position. This can be maintained long term as the volume of data increases.

The system uses degree rectangles (Figure 2), and each rectangle is defined by its southwestern coordinates. Thus all degree rectangles in Malaysian waters have a unique number, within which samples may be sequentially numbered. Existing samples will be given a new unique number and cross-referenced against the original number. The database has been designed so that onshore data may also be labelled using the degree rectangle system, though a different system for the collation of onshore data already existed in Malaysia.

A need to establish standardized data recording procedures was identified and BGS methodologies for onshore and offshore data are included as part of the databasing exercise. Paper forms which reflect the digital database table designs and separate information into distinct sections are provided for recording data in the field. Both index information, such as the location of onshore boreholes and offshore samples, and seismic data collection projects, and geological data, such as borehole lithology and particle size analysis, are recorded using these procedures.

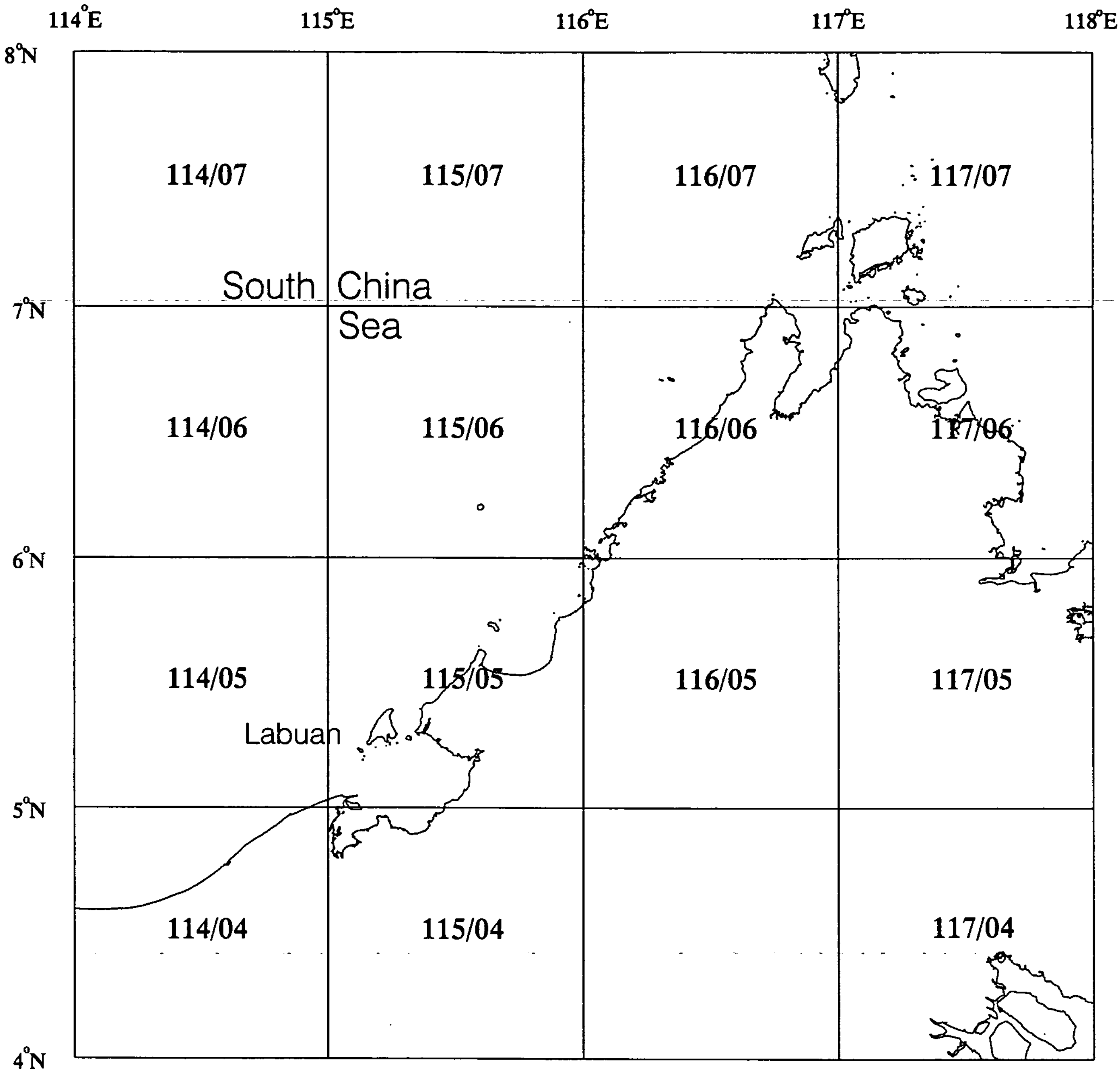


Figure 2. Extract of the degree rectangle numbering system devised for use in Malaysian waters.

BGS has dictionaries of logistical and geological terms which may be used within its digital databases, including lithostratigraphy, lithology, biostratigraphy equipment type, etc.. These dictionaries are linked to database tables to prevent the input of misspelt or unapproved terms. As part of the design of the database for GSM similar dictionaries were created, to be filled and linked to relevant tables at an appropriate stage during the database's development.

1.3.3 ORACLE Tables

Tables in a relational database management system (RDBMS) such as ORACLE are structured in a particular manner to reflect databasing conventions and efficient working practices. For each table, a unique identifier or 'primary key' is established. This is an element, or group of elements, (e.g. site number) unique for each set of data entered to that table, helping to prevent data duplication. Tables are linked to one another through their primary keys, which ensures that correct links are made. The tables reflect the contents of the input forms and the data may be selected on the basis of any one or more of the elements held in a table, or combination of tables.

In the example below the primary key of Table 1 is a combination of the degree grid square (latitude and longitude values) and the sample number, thus each row in the table is unique. The primary key of Table 2 includes the latitude, longitude, sample number and depth. These two tables may then be linked via their primary keys and the date and time of sampling for sites with more than 10% gravel ant less than 15 metres depth selected, for example.

Database tables should hold distinct data sets in order that different data types don't become confused and to reduce data duplication. An important objective of this approach is the separation of logistical information from scientific details. A table should be designed and created to ensure the minimum of duplication within the database and each table should be as compact as possible.

For example, when a core is logged by an external organisation, the name and address of that organisation may be recorded. When entering the geological information related to that core into a table the name of the organisation may also entered so that the originator of the data may be located. However, it is not appropriate to also enter the address of the organisation with the core data, this should be held in a separate 'address' table.

Table 1 Example of a database table

Lat	Long	Number	Date	Time
115	5	1	12-Mar-91	12:18
115	5	2	12-Mar-91	13:03
115	5	3	12-Mar-91	14:29
115	4	1	13-Mar-91	09:11
115	4	2	13-Mar-91	10:48

Table 2 Example of a database table

Lat	Long	Number	Depth m	Gravel %
115	5	1	10.04	10.5
115	5	1	17.89	18.0
115	5	3	21.45	82.2
115	4	2	12.76	7.5
115	4	2	19.43	7.5

1.3.4 Database design and implementation

The logical and physical designs of the BGS offshore and onshore database tables were analyzed for applicability to the project. The tables designed for GSM were based on those parts of the BGS databases relevant to the Malaysian application. Design of the database structure had to take account of the type of data being input, but also the estimated size of the database as a whole, and to which tables the majority of the data would be directed.

A two-tier database was designed, following BGS practices, whereby two identical sets of tables were installed, but direct input is only into the 'first-stop' temporary tables. Once the data have been validated they are transferred to permanent tables by the database manager. Users may access information held in both sets of tables, but only that held in the permanent tables is given any guarantee of correctness and accuracy.

Development of the database was carried out using a phased approach. The initial design and testing stages were performed on a replica database in BGS (Keyworth) during 1994. The ORACLE database was implemented in the Marine Group of GSM in November 1994, and during this period was modified according to the group's needs and data types. An initial training session gave basic user instructions to a small number of staff to allow input to and extraction from the database.

The third development phase was a second visit to GSM in July 1995. After a 6 month 'trial' period any problems with, or required changes to, the database were identified and modifications made. During the July visit alterations were made according to these requirements, and the efficiency of the database was improved through changes to its internal structure. All adjustments to the database were documented and explained to the database manager, and training provided in the management of the database.

1.3.5 Security of the database

The proper use of a carefully designed database provides an opportunity to store and maintain data in a standard and consistent manner. To benefit fully from the system the data collection forms must be used at all times to ensure the use of standard recording methods. Entry to the database via the digital entry forms is then vastly simplified and the integrity of the database data is maintained.

As mentioned above data validation and security are paramount in providing a high quality data set. The use of data collection forms and digital data entry forms helps to ensure input data is in a consistent format, so long as trained data entry operators are used. It is important that inputting data to the digital system is limited to staff who have basic training in ORACLE and specifically use of the digital entry forms. The data must first be entered into temporary tables and a printout of this information passed to the geologist(s), who collected the data, for checking and validation. Once any corrections have been made, again by the trained operators, the data may be moved from the temporary to permanent tables. The permanent tables may be viewed and output from them generated by any number of staff, with read-only access. Any subsequent editing must be restricted to a data manager, who has full access (read, write, delete, edit) to the database information. Although read access to the database can be permitted to a wide range of users, it is more efficient to limit extraction of data to those staff who use the system on a regular basis, ie. the data entry staff and data manager.

Provision was made within the design of this database for limited access to named users for input and retrieval of information, and for one database administrator/ manager, with open access. Other users will not be able to enter, delete, alter, or even view the coastal database information without permission being granted by the database manager. It is only the database manager who has authorization to transfer validated data from the temporary to permanent tables.

1.3.6 Organization of the database

The database is made of tables which contain specific boxes or fields. The tables are reflected by the input forms (Forms 1 to 14) addressing specific geological data. The database treats onshore and offshore data separately. For Coastal Zone Management issues tables from both components may need to be addressed. Tables have been set up to handle the following data:

Table	
A	GSM Site locational data and equipment data
B	Core Sample data
C	Grab Sample data
D	Non-GSM Site locational data
E	Particle size data
F	Gravity data
G	Onshore borehole locational data
H	Onshore borehole interval data
J	Seismic track line data
K	Seismic project limits
L	Geochemistry Heavy Minerals
M	Geochemistry Heavy Minerals - economic constituents
N	Geochemistry Minor/Major Oxides

Each form relates to one or more tables in the database. Note that the *site* may be the location of many *samples* collected using a number of devices or from a range of depths in a borehole.
Each form is considered separately below with descriptions of each table addressed by the

form. Although each form (see Forms 1 to 14) may exist as paper copy this will not always be the case. Forms 1, 2, 3 and 4 will usually exist within the paper archive, and will be entered into ORACLE using the digital forms; SQL*Forms V4.0 for the Malaysian system. All the other forms except Form 10 may not exist as paper records in this precise format, the data may come from other papers, and the details from these papers will be entered into ORACLE by filling in the digital forms. The information needed for Form 10 will be collected automatically on the vessel as the seismic data are collected and transferred subsequently into the data base under the guidance of the data manager. This form is included here to show how it is organised.

1.3.6.1 FORM 1: GSM site data - Table A

Logged by: the name of the member of staff who logged the data below, given first to follow GSM standard practices. A dictionary of staff abbreviations will be held in a separate table.

Cruise number: if more than one vessel is working at the same time, or if there are cruises in different areas then a cruise number allows differentiation between samples collected at almost the same time or place. The ship identifiers for each cruise will be kept in a dictionary held by the data manager.

Date: date of collection of the sample, where known.

Time: time of collection of the sample, where known, in local time.

Site number: the system for recording site data should allow samples from all areas likely to be investigated to be allocated an unique number. The proposed system, as described above, divides the study area into degree rectangles (see Figure 2) and defines that rectangle by its southwestern latitude and longitude co-ordinate. The Labuan area falls into degree rectangle number 115/05.

All degree rectangles within Malaysian territorial waters would have an unique number, and the degree rectangles being worked could also be allocated an unique name when activity commenced within that area. Thus an example of a full sheet title would be Sheet 115/05 - Labuan. This scheme divides Malaysian Territorial Waters into 88 degree rectangles, 35 covering western Malaysia and 53 covering eastern Malaysia. As all the sheets are north of the equator, and east of the Greenwich Meridian, there is no need to allocate +/- to the rectangle identifiers as both are always positive.

Within every degree rectangle each site is allocated an unique number starting from 1. Subsequent sites are allocated consecutive numbers. Existing sites in a degree rectangle may be entered into the database by allocating a degree rectangle number which is cross-referenced against its original number. When sampling commences within a degree rectangle the scientist should check the database to determine the number of the first site in each degree rectangle likely to be visited.

The degree rectangle numbering system is the basis for numbering all sites within territorial waters including boreholes, grab samples and beach samples. If the onshore sites are allocated a different numbering system then the landward limit for allocating degree rectangle numbers should be the high water mark.

Quarter: this refers to the quadrant of the degree rectangle, following onshore practices for GSM. This is not a compulsory field in the table, but may be required for near shore studies where on- and offshore data are to be used in unison.

Water depth: in metres to the nearest decimetre if known. It is assumed here that all depths are not corrected for tidal variation as it is unlikely that the data will be used to aid bathymetric surveys. Data collected from seismic surveys may be used for bathymetric surveys if the water depths are corrected for tidal variation.

Tidal correction: the default for this is the code NC for no correction made, however where a correction has been made it must be recorded, and the tide station from which it was made. Where the correction has been made from predicted tide, based on tide tables, TT is inserted: where a tide gauge has been used TG is inserted and TS where a tide station has been used.

Tide station: station from which tidal correction has been made.

Position: Both latitude and longitude (in the format of degrees and decimal minutes e.g. 115.4166°E is 115° 25'E) and the National Grid positions, are included. Only one needs to be filled in but a routine needs to be set up, outside of the database, which will allow conversion from one of the position fixing systems to another. The latitude and longitude should be calculated for all sites, however there may be sites outside the area covered by the National Grid, and in this case the Grid value will not be calculated. The Malaysian W/E box allows identification of the site in East or West Malaysian waters, though this can be worked out from the site number.

State: this two character field follows the onshore system for recording Malaysian state for providing information to management according to that criteria. Abbreviations for each code should be kept by the data manager.

Original site number: the typical system used by GSM at present is to allocate offshore sample numbers as follows:

20.9.93/SGM/0193/20/1154/Pla

Date/Survey Geology Marine/ cruise number/ line/ fix/ equipment type

The line and fix numbers refer to the seismic lines used to locate the site. Equipment type presently used include piston corer (Pla) and sea bed grab (S).

Each site is identified prior to the start of the cruise with the location, water depth, fix and line number, type of sampler to be used, and barrel size and length specified. On collecting the sample the time location, water depth, and a basic description are recorded on to a sheet. This system is adequate for limited surveys but will grow out of hand quickly if more cruises are undertaken. The inclusion of the original number in this table allows correlation within the database between the original number and the degree rectangle number.

Total depth: This is an indication of the length of sample recovered, which allows queries to be addressed to the database related to this length.

Test results: this field indicates whether geotechnical tests were carried out on the sample with the abbreviations used indicating the type of tests.

Additional information as free text: this space allows information which does not need to be added to the computer database to be included on the paper records.

Summary sample description: this is a 69 character description of the geology of the site, amalgamating available results from a number of different samplers. This is completed either during collection of the sample, or from a collation of data from the site after analysis of the samples.

Equipment type: samples should be marked up with the equipment type. Jar samples merely need the site number and equipment type, but annotation of cores is more complex. The sample equipment code is :-

Sg - Sea bed grab sample	Gc - Gravity core	Hs - Hand sample
Pc - Piston core	Vc - Vibrocore	
Dr - Dredge	Bh - Borehole	

The table allows up to 5 equipment types to be specified. Note that if a sea bed sample and core sample are taken at the same site then the equipment code will distinguish the two samples within the database.

Also included is an indicator, a four category code, of why no sample was recovered at a site. This is especially useful in highlighting areas of rock at sea bed where the sample technique was unable to recover a sample, or continuous equipment failure.

[The digital entry form which mirrors this paper form also includes two additional fields to point the computer to the next two tables for entry of data for core and grab samples.]

1.3.6.2 FORM 2: Sample description sheet

Form 2 is the free text description of the sea bed sample and any core. This is not to be put onto the database but acts as the paper record of the site. Form 2 will always be attached to Form 1 in the filing system where the paper records are stored.

1.3.6.3 FORM 3: Core sample data - Table B

Tables B and C may be used to input data on offshore boreholes from which logs or diagrams may be drawn using software outside the database

This table divides a borehole into a number of depth intervals and describes each in turn. A separate entry has to be made for each described interval.

Site number: this is explained above, and must correspond to a number given in Table A.

When using the digital entry forms this number will automatically be copied from the GSM site table (Table A).

Equipment type: the two character code giving the type of equipment used for extracting the sample. This will also be automatically copied from Table B when the digital input forms are used.

Layer: a numerical counter starting at 1 from the top to indicate the position within the core that this sample was taken at. The value can be calculated from the upper and lower depths given for each core sample. This layer is uniquely defined by the degree rectangle number of the sample, the equipment type and the upper and lower limits of the unit.

Upper depth: the depth from sea bed to the top of the section of core used for the sample.

Lower depth: the depth from sea bed to the bottom of the section of core used for the sample.

Lithology: primary and secondary lithologies of a sample are given in a format that can easily be selected for database queries, a more detailed description of lithology can be given in the sample description. GSM need to devise a dictionary of lithologies, a simplified version of the BGS dictionary is given in Appendix D.

Additional sedimentary parameters: a number of parameters of the sediment may need to be recorded on the database. These fields provide sites for the recording of data related to acid test on the sediment, mud strength and plasticity, the grain size, shape, sphericity and coral content of sand and gravel. The data may be generally subjective assessments recorded certain fields (e.g. well rounded to angular for grain shape) or as quantitative assessments recorded as figures (e.g. 30% coral content in sand). This field may also flag whether the sampling at the site reached bedrock.

Colour: this follows the Munsell Chart scheme or a standardised description and the classification adopted needs an unified approach. Suggestions for colour codes are contained in Appendix D.

A standardised field description might divide the colour into three fields, the first is the tone (dark to light), the second is the subordinate colour, and the third is the main colour. Thus **Lit/Yel/Gry** means light, yellow grey.

Biostrat/chronostrat/lithostrat: this three fold stratigraphic classification needs to be used in conjunction with a GSM wide stratigraphic code. If this is not available for use then local codes may be devised according to the geology of the area. GSM need to decide on these codes and devise a dictionary.

For offshore shallow cores an indication of "Holocene" may be the best that can be achieved. However, locally the "Holocene" may be made up of two or more units and these could be allocated a lithostratigraphic name and code. This subdivision becomes useful when the database needs to be interrogated for specific stratigraphic units.

Sample description: up to 250 characters may be used to describe the sample, the information given in the fields above may be expanded and additional information incorporated.

1.3.6.4 FORM 4: Grab sample data - Table C

The data entered into the table for grab samples is almost identical to that for core samples; sample number, lithology, mud, sand and gravel content, stratigraphical fields and sample description.

However there are no depth fields as only one grab sample will be taken with one piece of equipment per site. Additional fields are as follows:

Stored in: the degree rectangle number and equipment type are noted on each jar along with an indication as to whether the sample is stored in one or more jars. If the sample is from a core then there needs to be an indication on the jar or bag of the depth of the sample.

1.3.6.5 FORM 5 Non-GSM site data - Table D

This form incorporates locational, sample description, water depth and equipment information, similar to Table A, described above.

Additional information includes brief details on reports held by GSM. It assumes that the report has been carried out for a *client* by a *contractor,* and that the report has a number which will assist its location in the GSM archive.

Total depth metres: gives the maximum depth below sea bed of the samples described in the report.

As the information on this form may be gathered from confidential sources it needs to be separate from GSM sources. When information on an area is requested, both GSM and non-GSM sources must be specified for all information on the database to be extracted.

Typical non-GSM data are those collected during hydrographic or oceanographic surveys, or commercial aggregate, placer or pipeline surveys. Shallow drilling (placer or aggregate investigations) should also be included in this section. Deeper hydrocarbon wells are usually placed in a separate table.

This type of data includes both historic information and new reports coming into GSM. It is unlikely that samples will accompany the data, and the information may be limited or incomplete. Transferring this type of information onto the database may take substantial effort when the database is being set up, but provides invaluable background information on areas where no other data may exist.

1.3.6.6 FORM 6: Particle size data and Folk classification - Table E

This form uses tables H and I to record information on the particle size analysis of a sample, and to describe that sample under the Folk sediment classification scheme.

Site number: this is the site number from Table A.

Upper sample depth: if the sample is taken from a sea bed sampler then this is 0.00 m, otherwise it is depth below sea bed of the top of the sampled interval.

Lower sample depth: if the sample is taken from a sea bed sampler then this is a figure agreed for the sampler used. BGS use a figure of 0.15 m for a Shipek Grab, other sea bed samplers may have slightly different values. If the sample is taken from a core then the value is the depth of the base of the sample below sea bed.

Total weight of the sample: this is usually dry weight, determined after drying the sample. The sample is then sieved into its mud/sand/gravel components, the weight of each recorded, and the percentage of the original weight of each component is calculated.

% carbonate: included where the carbonate % of each fraction has been determined (either by a visual estimate for gravel, or by acid digestion for sand and mud).

% organic material: included where the % of organics have been determined for the whole sample and/or each fraction.

Quartz content: included where determined for the sand and gravel fractions by either visual or petrographic analysis.

Folk classification: the Folk classification of the sediment is worked out by a macro programme run on the table prior to loading the table into the database. The Folk classification is described in Appendix B. Other sediment classifications may be more informative especially where the sediments have a limited grain size range.

The Folk classification subdivides sediments into 12 fields based on a triangular diagram with mud/sand/gravel as end members. Each field is allocated a code (mS- muddy sand). The subdivision of the diagram is based on the mud/sand ratio of the sample and its gravel content.

Equipment type: the code are taken from Table A to indicate from which type of equipment the sample was taken.

1.3.6.7 FORM 7 : Gravity data - Table F

Number: this equates to the site number in Table A.

Position: given in latitude and longitude and National Grid as for locating other measurements in the database, with west or east and quarter grid square indicators.

Height in metres: the height above sea level at which the reading was taken.

Observed Gravity Value: this is the measured value

Bouguer Gravity Anomaly Value: this is the corrected and reduced value

Reference Report: this report describes the data collection and reduction methods

1.3.6.8 FORM 8: Onshore borehole logsheet - Table G

This form fills the same role as Table B but is for onshore boreholes.

GSM Drill Hole Number: this follows the numbering system used by GSM for numbering onshore boreholes.

Borehole Name: this is the specific name of a borehole.

Map reference: GSM map reference number on which the site is situated.

Position: National Grid co-ordinates are the primary locators here, with an indication of the location in Western or Eastern Malaysia. Latitude and longitude may also be given (or calculated at a later date) to fit with the other database tables.

Locality: this is a free format field of 50 characters where additional locational details about the site can be given.

Datum level: refers to the datum level of the borehole in metres relative to sea level.

Depth to rockhead: refers to the depth below datum in metres to rockhead.

Depth to base of borehole: refers to the depth in metres below datum to the base of the borehole.

Date of drilling: where known

Driller: name of the company who carried out the drilling.

Equipment: drilling equipment if known.

Some additional administrative information has been included on the paper form, and may be input to the database if considered to be required for future queries. The data include a GSM file reference number for cross-referencing purposes, and the names the GSM staff who *described* the borehole, were in charge of the drilling, the *typist* who entered the digital record. Dictionaries for the above fields need to be kept by the database manager.

1.3.6.9 FORM 9: Onshore borehole geology - Table H

GSM Drill Hole Number: following the numbers used for Table G.

As for Table B the *upper* and *lower depths* of each section of the borehole that samples are taken from are input, but in this case measure in metres from top of the borehole -the datum level.

Lithology, colour, grain size, mineral content, biostrat, chronostrat, lithostrat, strength, biogenic, structure and a 250 character *description* may be entered as for Tables B and C.

Descriptions of these fields should follow a standard approach which GSM need to implement. BGS has much experience in coding boreholes from the UK but GSM has a different system and should devise a scheme to follow local practise.

1.3.6.10 FORM 10: Seismic line data - Table J

Presently seismic data collected by GSM are marked up in the following way:

Sarawak Survey 21/7/92 Fix 2237-2516 Roll No.10.

The equipment type and sweep of the graphic recorder are usually written at the start of each line. Fix locations and water depth are recorded on a datalogger as the line is collected, with the fix number also marked on the paper record linking the two discrete sets of data. Another example of the marking of the rolls is:

Mersing Line 41-41-43 Roll 6.4 1-8-93

In this case Line numbers not fix numbers are used, and the roll number system is different to that employed for the Sarawak survey.

There is a need to standardise on the approach and to identify the seismic data more uniquely so that it can be placed into a territory-wide database. The approach suggested below follows the system used successfully by BGS over the past 20 years.

The suggested format allows inclusion of the relevant information onto the database; the form is shown here to indicate the data collected but in reality the transfer of data from the datalogger onto a table in the database would be carried out digitally by the data manager and there would be no need to use the on-screen digital form. The digital form displaying the table has the following fields

Year: each survey to be identified by the year it was run

Project: each survey to be given a name e.g. **Me** for Mersing, or a number. The data manager should hold a dictionary of the names or numbers.

Line: each line to be given a number (e.g. 04). Individual lines should be identified during a survey rather than continuous fixes producing a line with a complex rope-like plan and many hundreds of fix numbers. If this system is followed then there is no need for roll numbers.

Fix: each line should begin with Fix 1 and finish with the final fix in the data logger. The roll of paper should be separated into individual lines when it is used up. This makes interpretation very much easier than keeping a number of lines on one roll. Each line is therefore described as follows by :

Year/Cruise/line/fix numbers - 92/04/3/1-45 or 92/**Me**/3/1-45

Year/Month/Day: this data is entered into the data logger prior to the start of line.

Time (local): this is entered automatically onto the data logger.

Water depth: it is assumed that an echosounder is run at the same time as the seismic equipment and that the depth is put into the data logger automatically at every fix point. The water depth is not tidally corrected at this stage, though a routine could be written to correct the data for tidal variation using predicted or measured tides at a nearby port.

Position: the position at every fix point is automatically recorded by the data logger. The information could be in latitude and longitude or National Grid co-ordinates, with post-cruise manipulation to ensure that both are entered onto the database. The location of the profile in Western or Eastern Malaysian waters would help locate the line and ensure that the correct National Grid was used.

Equipment: each piece of equipment used would be entered here to ensure that each profile is identified. it is common practise to run together an echosounder, sidescan sonar and boomer. The codes used are :

Ss - Side scan sonar	Sp - Sparker	Pr - Pinger
Bo - Boomer	Ec - Echosounder	Mg - Magnetometer

These can be changed or expanded as required.

It is important to record all the necessary equipment parameters (such as sweep time, filter settings) at the start of each line. One means of achieving an uniform result is to have a stamp or sticky-backed proforma which can be put at the start of the line on which these data need to be infilled; a second end of line marker with less information is also useful to the seismic interpreter. Figure 4 shows tracks of seismic profiles around Labuan stored on PCORACLE and made into a map using the Atlas Mapmaker programme.

1.3.6.11 FORM 11: Seismic project limits - Table K

This form is intended to show the general limits of seismic projects. GSM seismic data have been collected from a wide range of areas, such as Darvel Bay and off Mersing, and without such a table it will be difficult to keep a track on the areas covered without printing out all the seismic lines. Such a facility is essential if the database is to handle information over the next decade or longer.

Project: this is the Project name from Table J

Year: year of running the project

Number of records: this is the number of seismic lines run for the project and provides a crude indication of the volume of data available. A better but more time consuming estimate would be the line-kilometres in the project.

Project limits: this gives the geographical limits of the project as a rectangular shape. The limits are given as both latitude and longitude, and National Grid co-ordinates

1.3.6.12 FORM 12: Geochemistry - Heavy minerals - Table L

Site number: this is explained above, and must correspond to a number given in Table A.

Sample type: whether the analyses were performed on core or grab sample.

Original number: GSM original site number (as explained for Table A above).

Filename and location: refer to GSM filing and site naming conventions.

The *weight* of the *sample* and of the *heavy minerals* and *gold* found within it are given.

Size fraction: this identifies the grain size of the sediment on which the analysis was carried out. It could be the whole sample, a sub-sample defined by a description (e.g. fine sand) or defined by phi grades (e.g. 0 to 1 phi)

The second table containing heavy mineral data (**Table M**) gives the breakdown of economic mineral constituents. If trace amounts of any element are found these are recorded as -99.

Upper and lower depth relate to core sample depths (see Table B).

1.3.6.13 FORM 13: Geochemistry - Oxides - Table N

The site number, GSM filename and sample weight are input as for Table L.

Sample type: whether this is a sediment or water sample.

Depth: the depth of the sample beneath the sea bed. This needs an upper and lower limit.

Equipment type: core or grab sample, using a convention from Table A

The % content for the chemical constituents are then given for 14 elements.

1.4 OUTPUT FROM THE DATABASE

The database can produce output as lists of information related to specific queries (see Appendix B of Part 3 of this report), or as maps displaying the data graphically.

The data lists are the product of interrogation of the database; summary sample descriptions and positions of data within a set degree rectangle are an example of the data which can be requested. The data are extracted using SQL queries run on the database. The precise form of the queries depends on the required information, but a number of standard queries may be established and SQL*Plus code written in advance to enable the user to perform repeat tasks without repetition of effort.

Data may be selected from a single table or a combination of two or more tables. Auditing of the database may be required to provide project managers with information regarding the number of entries in the database for a particular data type or for a particular area. For example, the total number of offshore sites sampled around Labuan (within a defined area) and the number of grab and core samples extracted for those sites can be calculated.

To produce maps from the database requires the data extracted by running an SQL query to be put into a map-making programme. Maps showing seismic track lines (Figure 4), sample site locations and numbers of borehole sites, for example, can then be generated. This is explained in more detail below.

Typical queries which may be answered from the database are:

1. The coordinates of all sample sites for a project area, delimited by given coordinates of a rectangle (the same limits to be used later in the plotting software to produce a location map).

2. List of the Folk classification of all sample sites in water depths less than 50 m within a specified the project area.

3. Location of all sea bed sediment sites with greater than 50% gravel content.

4. Location of all onshore and offshore boreholes which contain Quaternary deposits.

5. The lithological breakdown as a listing of all the boreholes in a project area.

6. The coordinates of seismic lines recorded during 1993. (To be used later in the plotting software to produce a track-plot map).

1.5 MAPMAKING FROM THE DATABASE

The data extracted from the database (e.g. locations of sites in a certain area) are usually displayed on a map. The software to produce such a map resides outside the database: it needs to be able to produce maps at range of specified scales, with a range of text, and to a range of printers.

For the majority of mapping packages, including those used for this study, the input data must be a list of coordinates labelled as either point or line features. This may require some editing of the data file extracted from ORACLE, and for frequent operations a standard routine may be written to extract and edit the database listing.

Before the map making software can operate properly decisions need to be made regarding the map projections and coastlines used within the program. This requirement needs to assess the long-term needs of the database users, and the geographic (scale, projection, size) parameters of the paper maps to be used alongside the computer generated maps. The facility should exist to make the computer generated maps compatible with both the existing and future land (topographic) maps and offshore maps. Figure 3 shows a map of gravity data collected on Labuan island. The coastline was digitised from the 1:25 000 scale road map of Labuan, transformed into Mercator projection and then translated into a map using Atlas Mapmaker software.

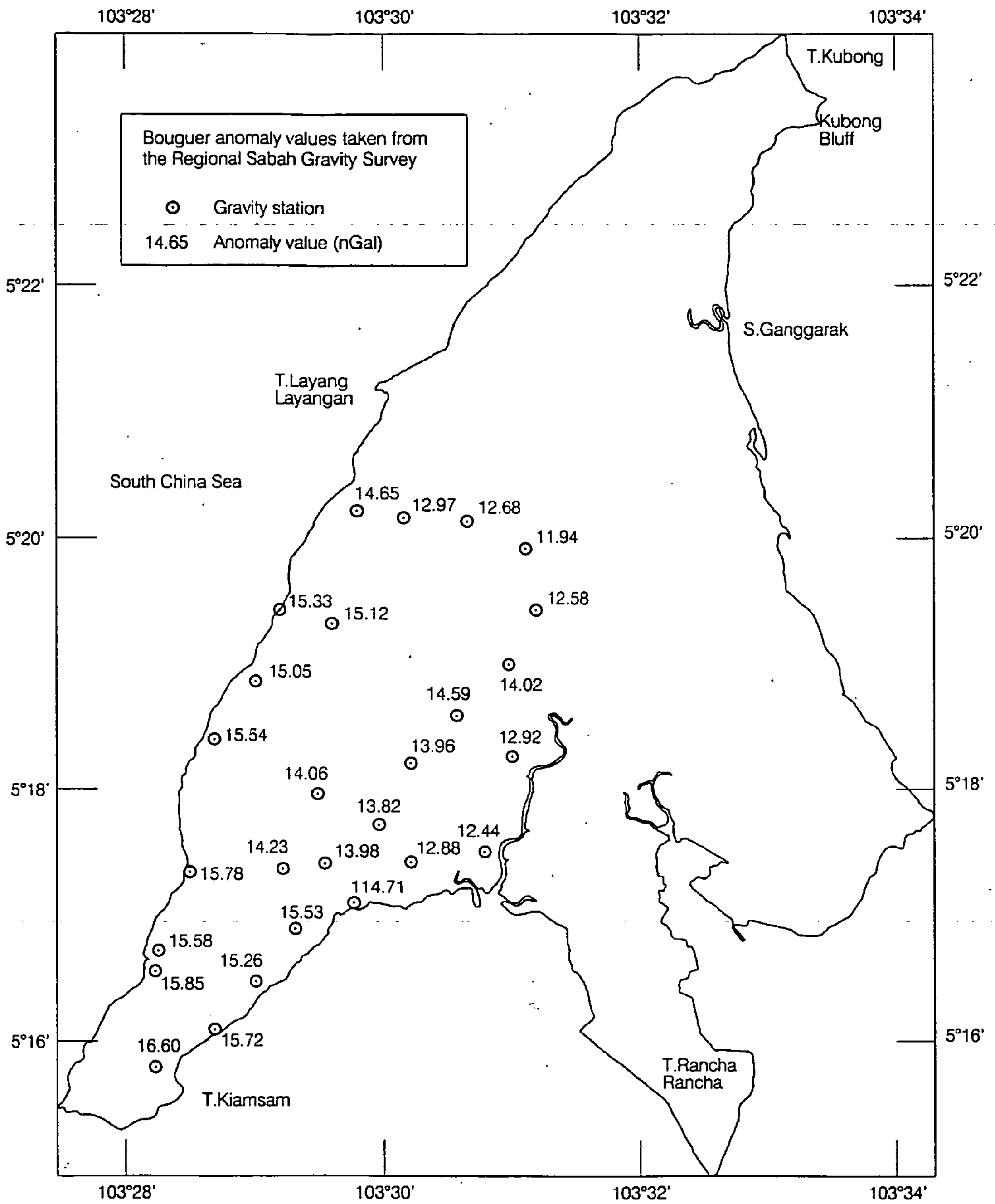


FIGURE 3. Selected Bouguer anomaly values for Labuan.

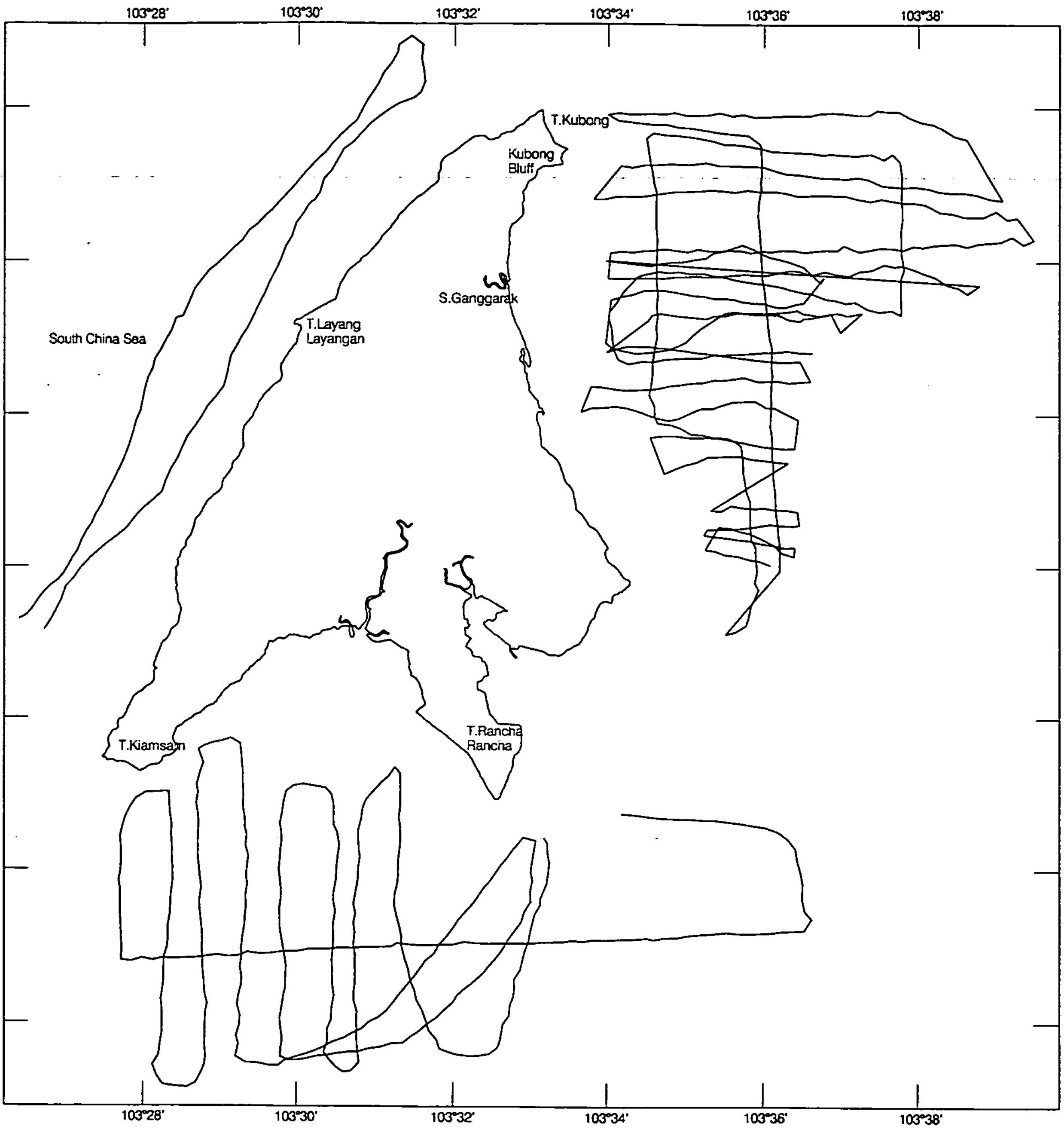


FIGURE 4. Seismic track lines from the surveys around Labuan

1.5.1 Projections

The map making software attached to the database should allow maps to be generated of the coastal zone and all of the offshore territorial waters of the country. Often the standard projection for the land area of a particular country is not designed to cover also all of its territorial waters. Therefore the map making software may need to be able to generate maps at a number of projections.

The specific map projection to cover the coastal zone varies country by country, being dependant on the geographic shape of the country and historic choice of projection for the national series of topographic maps. The aim is be able to produce maps which can be overlain on the base maps used by other coastal zone projects. Before the project commences the maps series to be used for the coastal zone must be agreed and the projection for these maps will then be the one used to produce the computer-drawn maps.

For the offshore territorial waters the hydrocarbons industry generally uses the Universal Transverse Mercator (UTM) projection. This projection has global application but is limited by being divided into zones 6° of longitude across. Maps with a longitudinal width greater than 6° can be created using the UT projection by artificially widening the zone, but this introduces inaccuracies.

The simplest course of action is to chose another projection for such longitudinally extensive areas, and the Mercator projection is a suitable choice in low latitude countries.

1.5.2 Projections for use in the Malaysian coastal zone and territorial waters

The Malaysian land area is covered by two Rectified Skewed Orthomorphic (RSO) Projection Grids, one covers Western Malaysia and one covers Eastern Malaysia. The limits of these grids are shown on Figures 5 and 6. These grids do not cover the whole of Malaysian waters and a different projection needs to be used for the Malaysian territorial waters outside the limits of the RSO grids.

The (UT) projection is the projection used by BGS for the production of its 1:250 000 maps series of the UK continental shelf. Each UT zone has a longitudinal width of 6°. Thus Malaysia stretching from about 99° E to 120° E, embraces five UT zones. Producing an accurate map showing all Malaysia territorial waters cannot be achieved by simply using UT projection.

The Mercator projection is well suited to display Malaysian territorial waters which are stretched parallel to the central meridian of the projection (the Equator) and have a limited latitudinal range (1° N to 9° N). Figure 2 showing the degree rectangle numbers of map sheets across Malaysian waters was produced using a Mercator projection.

The map making programme devised for this stage of the project are therefore the two RSO projections for areas near the coast, and the Mercator projection for maps covering more extensive areas of Malaysian waters. The option to use the UT projection could be introduced into the database at a later stage so that maps of the offshore waters could be produced that were compatible with hydrocarbons industry data.

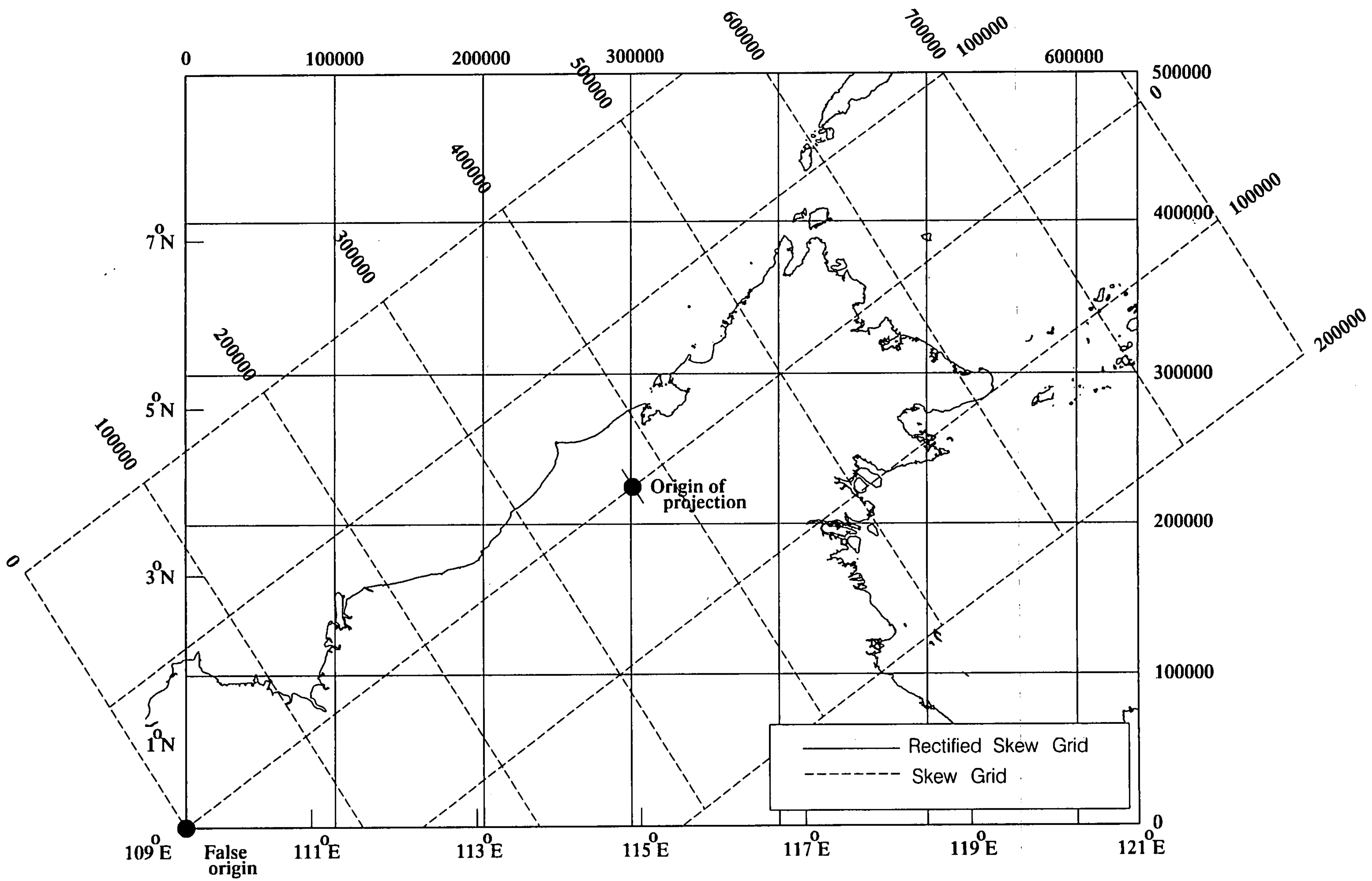


FIGURE 6. Extent of RSO projection for Eastern Malaysia.

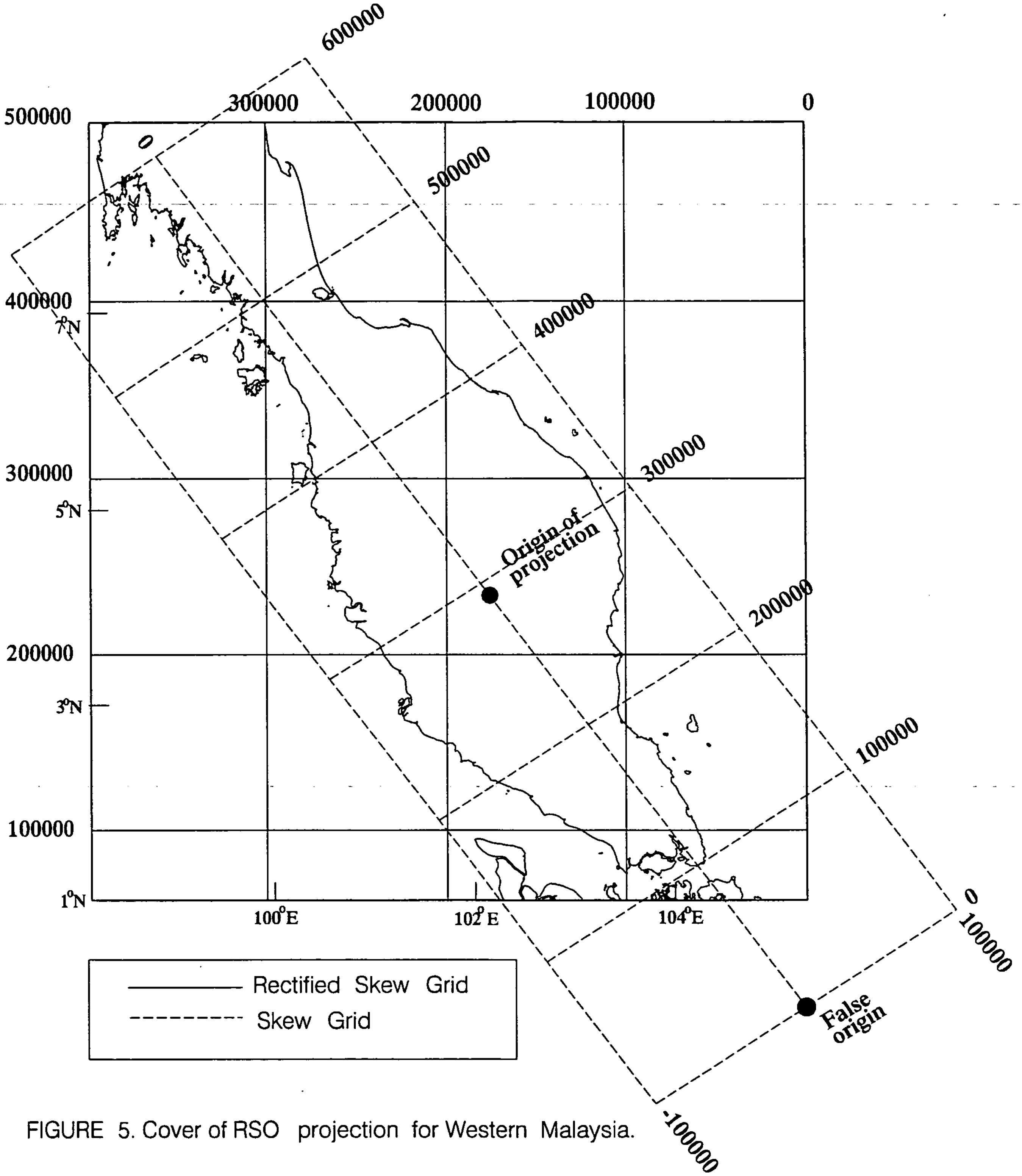


FIGURE 5. Cover of RSO projection for Western Malaysia.

1.5.3 Coastlines

Digital coastlines to drop onto the maps produced by the computer may be produced either by digitising existing maps or by using an existing digitised coastline file. If coastlines are to be digitised from existing maps then the full details of the projection of the paper map need to be known.

If the coastline is digitised in lat/long co-ordinates then it can be converted to RSO, Mercator, or other projections using specialist software. The Intergraph Projection Manager software is used in BGS to convert graphical data between projections. A programme for converting coordinates to and from lat/long and RSO for east and west Malaysia had already been made available to GSM. This was written in BGS by Alexander and Williamson, and allows ascii files (coordinate lists) of projected data to be converted into using Fortran programmes.

CD-ROM are available which carry world coastlines, in ascii format. The coastline on Figures 1a and 1b were created from the *World Vector Coastline* produced by the USA National Oceanographic and Atmospheric Administration. This coastline is adequate for maps at a scale of about 1:1 million but at larger scales it does not carry enough detail.

Figures 4 and 5 in Part 1 of this report were produced by digitising the 1:25 000 scale Labuan road map. The topographic map of the island not being available for the study.

When considering the range of coastlines to be used in combination with database data consideration must be given to the scale of the maps required and areas to be covered. The GSM or body in charge of the database need to consider what type of map they will need to produce in conjunction with the database. In the case of Malaysia, coastlines of specific areas could be digitised from the existing 1:50 000 topographic map series as the need arises and in time the detailed coverage available to the map making soft ware would expand. More general maps could be generated from the *World Vector Coastline.*

1.6 EXTENDING THE SYSTEM

An important consideration when devising a database is the future use of its data. In many cases the production of maps and tables of logistical data are the required output, and these may then be further interrogated. With the advent of GIS the majority of map-based, and some mathematical analyses can be carried out within one system, including the database. The availability of a digital system that enables extraction of database information, generation of graphic output and the ability to combine and expand numerous data sets greatly enhances the flexibility of the database and its use.

Since the early 1990s GIS have been increasingly used internationally for coastal zone management. Riddell (1992) attested that GIS could respond to the growing need for an integrated approach to coastal zone problem solving. He noted that a multi-disciplinary approach could be taken and that the requirements of a wide range of users may be encompassed, providing a valuable source of information for decision makers.

In Belize a data sharing agreement has coordinated efforts of several environmental data collection agencies for the coastal zone, enabling effective management for a country with low resources and a growing skill base (Gill, 1995). An important part of their system is the use of GIS to combine data sets to produce resource maps to judge the competing demands on the country's resources.

For this study a GIS was not utilised as it is of paramount importance that a proper database is established first, before an expansion into a GIS is considered. The standardisation of methodologies, installation of the database and data entry were tackled in order to lay the foundations for further developments with the Malaysian coastal data sets. The potential for incorporation of the database into a GIS was recognised and discussed as an option for the future.

APPENDIX A: MARKING UP CORE

The aim is to introduce a standard means of making core which accords with the database.

If the core recovered is too long for storage then it will need to be cut into a set length determined by the onshore storage system. BGS cuts core into 98 cm lengths which fit into 1 m boxes. Each section of core is given a letter starting with " a " being the top piece, and an indication, such as "a/3", that this is part "a" of a core which has been cut into three pieces. Note that the division of the core is not recorded on the database.

Figure 7 shows a typical marked up core. Note the line down the centre of the core along which it will be cut and the duplication of the numbers on both sides of the line so that identification of both core halves can be made after cutting. The arrow indicates the way up direction of the core and normally the annotation is made with the top to the left. To limit confusion regarding the top and bottom of a core length BGS has yellow caps for the top and black caps for the bottom of each core length.

CORE SECTION
Core cut to standard length

← 115/05/53 a/3 ←
← 115/05/53 a/3 ←

WHOLE CORE
Top Bottom

← a/3	← b/3	← c/3

Figure 7 Marking up offshore cores

APPENDIX B: SEDIMENT CLASSIFICATION - THE FOLK SYSTEM

Pettijohn (1975) describes a number of classifications of "sedimentary aggregates". Whilst there is general agreement with respect to the terms applied to individual grains or fragments, no such agreement has been attained concerning the names to be applied to an aggregate of such fragments - the sediment. All of the schemes have limitations and the choice generally depends on the available data and grain size range of sediment to be classified. The BGS have used a scheme devised by Folk (1954) to subdivide the sea bed sediments on the UK continental shelf (Figure 8). This was used because the sediments ranged from mud to coarse gravel. If the sediments were more constrained grain size then a different system might be considered.

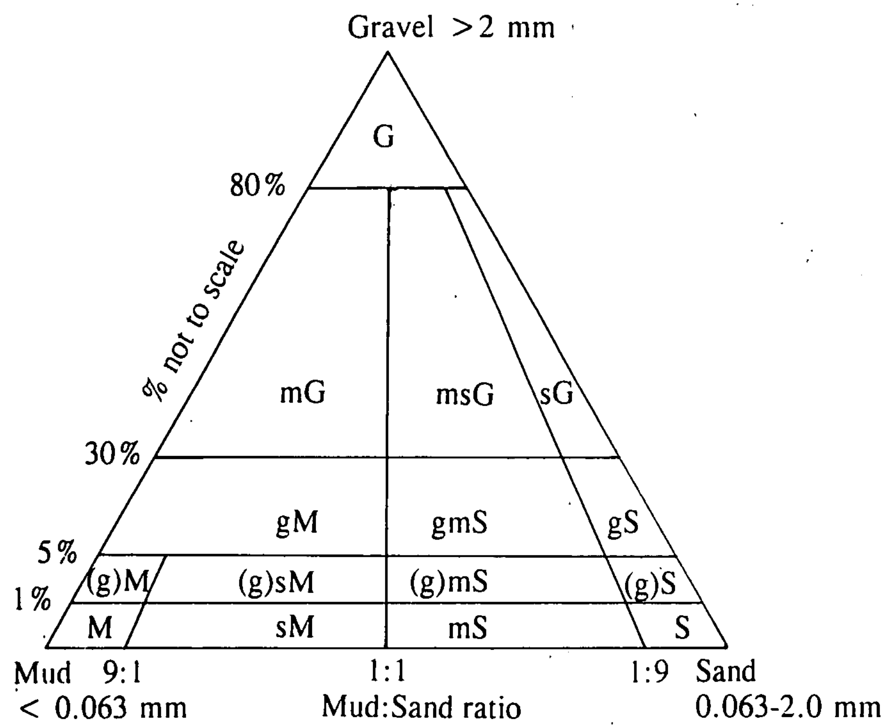
The standard three-fold major grains size categories defined by Wentworth gravel (>2 mm) sand (2 mm - 0.0625 mm) and silt and clay -collectively known as mud (<0.0625 mm), were used by Folk (1954) to construct a triangular diagram with the textural groups (or sediments) defined by the mud/sand ratio of the sediment and its gravel percentage (Figure 9). The BGS use a gravel percentage of 1% to divide the lower tier of groups whereas Folk (1954) used *trace* as the criteria.

This scheme works well where there is a wide range of textural groups but may not be adequately expansive where the sediments are predominantly fine sand and mud. Folk (1954) proposed a second classification based on the expansion of the lower tier of Figure 8 with Sand, Silt and Clay as end members. The textural groups in this diagram were defined by the sand percentage and silt/clay ratio in the sediment.

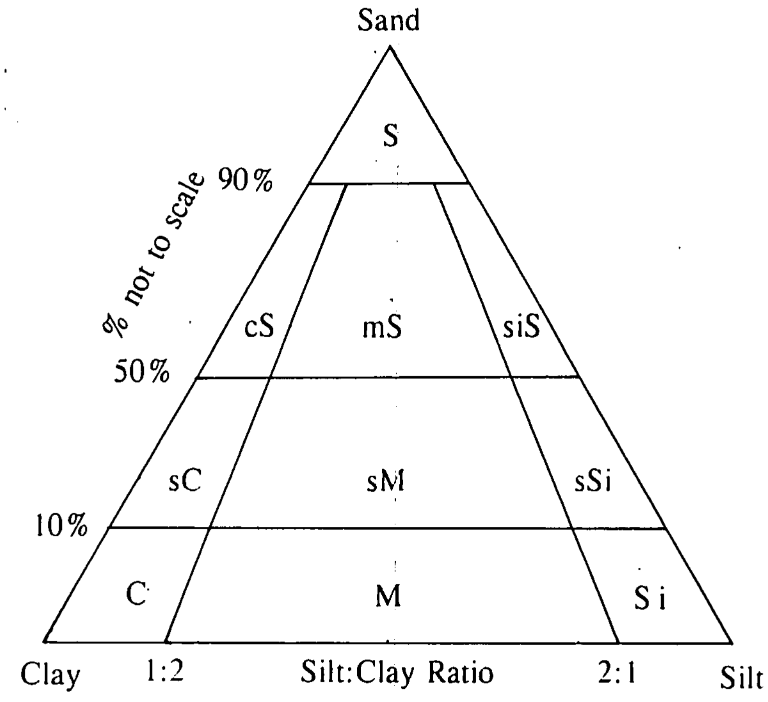
Note that Figure 8 requires an accurate assessment of the clay/silt ratio within a sediment which is a long winded process using either pipette analysis or one of the modern automated sediment analyzers.

A point to bear in mind is that engineers and those involved with sediment as an aggregate resource do not use the same grain size boundaries as geologists. The aggregate industry in the UK use 5 mm not 2 mm as the gravel/ sand boundary. This leads to confusion with the 2 mm to 5 mm interval being termed "sand and gravel". When particle size analysis is being carried out separation of the >5 mm gravel fraction would provide useful information for later resource studies.

On the Wentworth (1922) scale the silt/clay boundary is 1/256 mm (0.0625 mm or 6.35 microns). Civil engineers use 0.04 mm (4 microns) as the silt/clay boundary. This needs to be considered when external data are used which may not carry the full indication of the grain size limits used.



Note that in this classification the gravel content is noted at > 1% gravel, whereas in the original classification (Folk, 1954), the cut off is at a "trace" of gravel



Expansion of the bottom tier of the classification in the diagram to the left

Figure 8 The Folk (1954) unconsolidated sediment classification

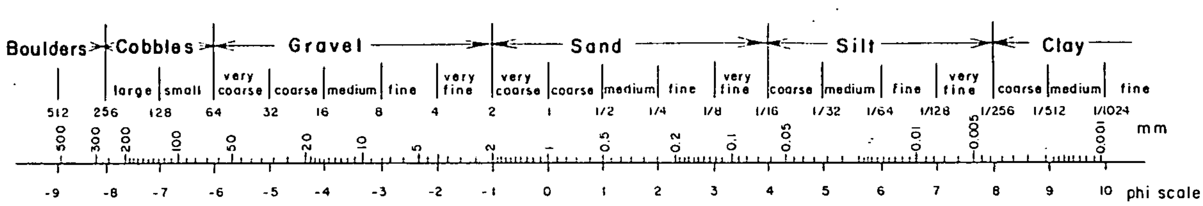
APPENDIX C: THE WENTWORTH SEDIMENT CLASS LIMITS

Wentworth (1922) divided the sediment classes on a geometric scale into a number of categories as shown in Figure 9. This division is now widely accepted.

To avoid irrational limits and to simplify statistical calculations Krumbein (1934) proposed the ϕ (phi) scale, where the exponent (logarithm to the base 2) of the diameter is used instead of the diameter in mm. Thus 4 mm is 2^2 and 1/2 mm is 2^{-1}. To avoid negative numbers the log was multiplied by -1 (Figure 9).

$$\phi = -\text{Log}_2 \text{ diameter (mm)}$$

Thus 2 mm (sand/ gravel boundary) is -1ϕ, and 0.0625 mm (sand/mud boundary) is 4ϕ.



From Pettijohn, F J. 1975. *Sedimentary Rocks*. Harper Row New York

Figure 9 The relation between the Wentworth class limits and the phi(ø) scale

APPENDIX D: CODING OF SEDIMENTS

Before the borehole data sheets are completed there needs to be a standard code issued to all filling in the sheets covering the description of the sediments within boreholes. These descriptions need to be consistent with sea bed sediment descriptions in terms of parameters such as colour strength etc.

It is not possible at this stage of the project to put forward a code to cover all sediments, but an attempt is made below to produce a simple range of codes for unconsolidated sediments. This list should be amended with time or to accord with local existing schemes. There is a need for the scheme to be universally accepted within an organisation or group so that the database queries will be comprehensive.

Lithology	**Size**	**Colour**	**Strength**	**Biogenic**	**Structure**
C- Clay	Cg-coarse	Blk-black	V-very soft	Rot-roots	Lam-laminated
Z- Silt	Mg-medium	Blu-blue	S-soft	Shl-shells	Cro-cross-bedded
M- Mud	Fn-fine	Brn-brown	F-firm	Pea-peat	Fla-flaser
S- Sand		Grn-green	T-stiff	Wod-wood	Uni-uniform
G- Gravel		Gry-grey	Y-very stiff	Bit-biotur'ed	
p- Peat		Orn-orange	H-hard	Cor-coral	
		Pin-pink			
		Pur-purple			
		Red-red			
		Yel-yellow			
		Whi-white			
		Drk-dark			
		Lit-light			
		Pal-pale			

Form 1

GSM SITE DATA

Marine Geology Group Geological Survey of Malaysia

Logged by

Site Number
+Lat +Lon No

Cruise Number
Year Ship No

Date
Mnth Day

Time (local)
Hrs Mins

POSITION

Latitude
Degs Mins (decimal)

Longitude
Degs Mins (decimal)

Easting

Northing

Malaysia(W,E)

Water Depth (m)

Tidal correction

Tide station

State

Quarter

ORIGINAL SITE NUMBER

ADDITIONAL INFORMATION - FREE TEXT

Total Depth (m)

CP test
Y or N

SP test
Y or N

EQUIPMENT TYPE

1 2 3 4 5

1. Sample recovered
2. No sample (geol reason)
3. No sample (equip failure)
4. No sample undifferentiated

Sample Recovered?

SUMMARY SAMPLE DESCRIPTION

Form 2

SAMPLE DESCRIPTION SHEET

Geological Survey of Malaysia: Marine Geology Group

SAMPLE NUMBER

+	+	

SEABED SAMPLE EQUIPMENT USED:		Stored in: Jars	Bags

CORE SAMPLE	EQUIPMENT USED	Stored in: Cut cores	Uncut cores	Jars	Bags

Depth	Log	Description	Core photo Yes / No	Sub Samples	Geotechnology
1					
2					
3					
4					
5					
6					

Form 3

GSM CORE SAMPLE DATA

Marine Geology Group Geological Survey of Malaysia

Sample Number

Lat. Long No. of grab

Equipment Type

Lithology

minor major

HCl result

Layer

Upper Depth

Lower Depth

MUD

Hardness Plasticity

SAND

Grain Size Shape Spericity Coral Content

GRAVEL

Grain Size Shape Spericity Coral Content

Total Content

Humic Coral

Contact

Colour

Biostrat

Chronostat

Lithostrat

Strength

Biogenic

Structure

Sample Description

Form 4

GSM GRAB SAMPLE DATA

Marine Geology Group Geological Survey of Malaysia

Sample Number
Lat. Long No. of grab

Equipment

Lithology
minor major

HCl result

MUD
Hardness Plasticity

SAND
Grain Size Shape Spericity Coral Content

GRAVEL
Grain Size Shape Spericity Coral Content

Total Content
Humic Coral

Colour

Biostrat **Chronostat** **Lithostrat** **Strength** **Biogenic** **Structure**

Stored in
Jar num Bag num

Sample Description

Form 5

NON-GSM SITE DATA

Marine Geology Group Geological Survey of Malaysia

Site Number — +Lat, +Lon, No

Date — Yr, Mnth, Day

Time (local) — Hrs, Mins

Water Depth (m)

Tidal correction

Tide station

ORIGINAL SITE NUMBER

POSITION

Latitude — Degs, Mins (decimal) 32

Longitude — Degs, Mins (decimal) 40

Easting

Northing

W,E Malaysia

State

Quarter

ORIGINAL SITE NUMBER

ADDITIONAL INFORMATION - FREE TEXT

SUMMARY SAMPLE DESCRIPTION

REPORT DETAILS

Client

Contractor

GSM Report No

T.D in metres

Equipment Type — Sg Pc Vc Gc Bh Hd Dr

Form 6

PARTICLE SIZE DATA

Marine Geology Group Geological Survey of Malaysia

Site Number

+Lat +Lon No

Upper sample depth (m)

Depths below sea bed

Lower sample depth (m)

Total weight of sample (grms)

% gravel

% sand

% mud

% organic in gravel

sand

mud

Sample total

% carbonate in gravel

sand

mud

Sample total

% quartz in gravel

sand

Folk classification code

Equipment type

Sg Pc Vc Gc Bh Hd Dr

FOLK CLASSIFICATION

Folk code

Folk classification

Sand / mud ratio min. value

Sand / mud ratio max. value

Gravel % min. value

Gravel % max. value

Form 7

GRAVITY

Marine Geology Group Geological Survey of Malaysia

NUMBER

POSITION

Degs Mins (decimal) Degs Mins (decimal)

Easting

Northing

Malaysia (W,E)

HEIGHT

OBSERVED GRAVITY

FREE AIR

BOUGUER REDIRECT

INNER ZONE

INNER CODE

OUTER ZONE

OUTER CODE

BOUGUER GRAVITY

BASE CODE

Form 8

ONSHORE BOREHOLE LOG SHEET

Marine Geology Group Geological Survey of Malaysia

GSM Drill Hole No.

Borehole Name

Map Reference

POSITION

Latitude

Degs Mins (decimal)

Longitude

Degs Mins (decimal)

East

North

W/E

Quarter

State

Locality

File Reference

Driller

Date of Drilling

Day Mnth. Yr.

Equipment

Depth to RH

Depth to Base

Datum

Water Table (cm)

Form 9

ONSHORE BOREHOLE SAMPLE DESCRIPTION

Marine Geology Group Geological Survey of Malaysia

Drill Hole No.

File Reference

Upper Level

Lower Level

Lithology

Colour

SnO_2 Content

Minerals

Biostrat

Chrono

Lithostrat

Grain Size

Median of Sand Fraction

Strength

Biogen

Structure

Description

Form 10

GSM SEISMIC LINE DATA

Marine Geology Group Geological Survey of Malaysia

Project

Line

Fix

Year

Month

Day

Time (local)

Water depth (metres)

POSITION

Latitude

Degs

Mins (decimal)

Longitude

Degs

Mins (decimal)

Easting

Northing

W,E Malaysia

Equipment

Ss Sp Bo Ec Pig Mg

Form 11

GSM SEISMIC PROJECT LIMITS

Marine Geology Group Geological survey of Malaysia

Project

Year

Number of records (lines)

Project limits

Minimum latitude

Degs Mins (decimal)

Maximum latitude

Degs Mins (decimal)

Minimum longitude

Degs Mins (decimal)

Maximum longitude

Degs Mins (decimal)

Minimum Easting

Maximum Easting

Minimum Northing

Maximum Northing

W E Malaysia

Form 12

GEOCHEMISTRY OF HEAVY MINERAL CONCENTRATION

Marine Geology Group Geological Survey of Malaysia

Site Number

Lat Long No.

Sample Type

Original Number

Filename

Weight of Heavy Minerals

Weight of Sample

Location

Size Fraction

Gold Weight

-00.03 if below detection limit

Heavy or General?

Form 13

GEOCHEMISTRY OF HEAVY MINERAL CONCENTRATION ANALYSIS

Marine Geology Group Geological Survey of Malaysia

Upper Depth

Site Number

Lat Long No.

Filename

Lower Depth

Sample Elements Geochemistry (Economic Minerals) ppm

Pb Ni Co Ag Mo Cu Zn

Fe Mn As Sn W U Hg

Sb Bi Bn Cr V

If trace amounts of element found input -99

Form 14

GEOCHEMISTRY- MINOR/MAJOR OXIDES ANALYSIS

Marine Geology Group Geological Survey of Malaysia

Site Number

Lat Long No.

Filename

Sample Weight

% content

SiO_2 Al_2O_3 Fe_2O_3 FeO MgO CaO Na_2O

K_2O TiO_2 P_2O_5 MnO LOI H_2O^+ H_2O^-

2. CASE STUDY OF PULAU LABUAN, MALAYSIA

2.1 INTRODUCTION

Pulau Labuan is a triangular shaped island of approximately 92 km^2 lying at the entrance to Brunei Bay, to the west of Sabah, Malaysia, and northeast of Brunei (Figure 10). The island is administratively part of the Federal Territory of Malaysia. Little of the original tropical rain forest persists on the island which is covered by mixed agricultural vegetation, strandline vegetation, or wetland of mangrove or freshwater swamp.

A channel between 5 km and 10 km wide separates the eastern shore of the island from the Sabah mainland to the east (Figures 10 and 11). The topography of the island is generally flat or undulating, with the highest ground formed by a NE-SW trending ridge in the northern part of the island which reaches a height of 92 m. The island has a good road system, and the main town is Victoria, in the southeastern part of the island, where most of the oil-related industry is based. Pipelines carrying hydrocarbons from offshore production fields reach shore at the southwestern corner of the island, a pipeline carrying water from Sabah lands at Rancha Rancha and an electricity cable lands south of S. Ganggarak (Figure 10).

Legislation was passed in 1990 to make Labuan into an offshore financial centre and this has led to much proposed major infrastructural development on the island. GSM are investigating some of the geological aspects of the developments and have carried out a number of projects on the island to aid these investigations. In 1990 a shallow drilling programme was carried out in the intertidal zone off the east coast of the island (Chow Weng Sum, 1992) and in 1991, with the assistance of CCOP, GSM carried out a shallow seismic reflection profiling survey around the island, supplemented by sea bed sampling (Vijayan and others, 1992). Additional seismic refraction profiling had been carried out in some of the intertidal zone to determine the thickness of unconsolidated sediments (Jawatankuasa Technikal, 1991) on which building may take place.

These projects along with other sources, provide the data to be put into the database described in Part 1 of this report.

2.2 CLIMATE

The following information is taken from the China Sea Pilot, Volume II (Hydrographic Office, 1992) and James (1984). The mean daily maximum temperature on Labuan varies between 30°C and 32°C and the annual average precipitation is 3766 mm.

The wind directions for the year at Labuan are shown in Figure 12 and the mean wind speed is uniform throughout the year at between 6 and 7 knots (3 m to 3.5 m /sec). A third of the observations on Brunei recorded calm conditions. The area experiences a monsoonal wind pattern blowing predominantly from the northeast from December to March, and from the southwest from April to December (Figure 12). Gales of force 7 and above occur for less than 5% of the time in December and less than 1% of the time in May. The monsoonal winds are rarely strong and sea states are mainly slight with only 20% frequency of moderate states. The area lies well south of the track of typhoons, which in the South China Sea

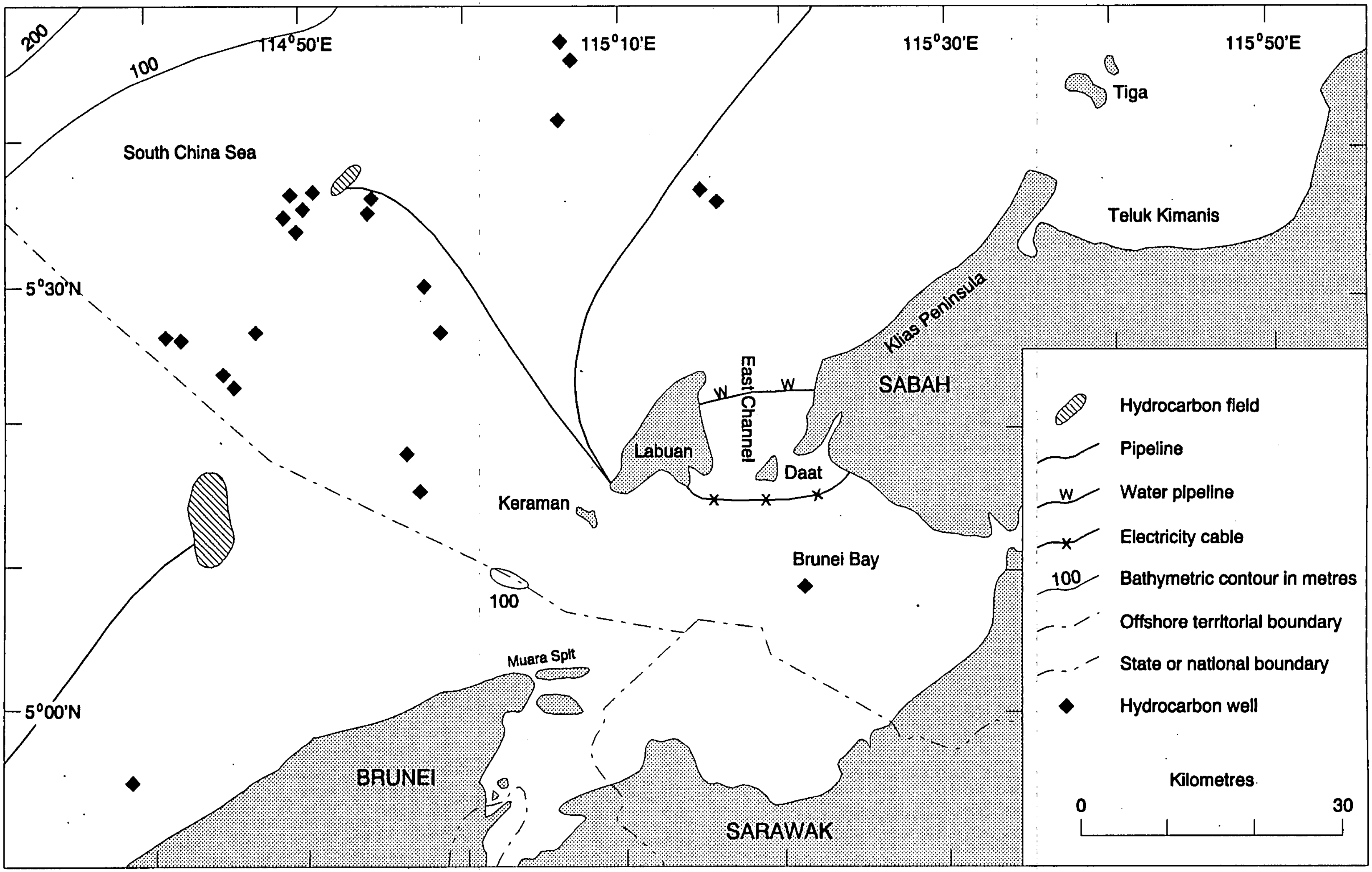


Figure 10 Location of Labuan, Malaysia

generally occur only north of 10°N. Typhoons tracking through the northern part of the South China Sea may generate swell which reach the coast, and James (1984) reports waves with a significant height of 3 m or more being associated with these rare conditions.

The wind direction is dominant in dictating the offshore currents: though the most prevalent mean wind direction is from the southwest (Figure 12). Chua and Mathias (1978) report that the dominant longshore drift direction along the coast of Labuan is from north to south. James (1984) reports net sediment transport in a similar direction, parallel to the coastline, of western Brunei. This contrasts with the evidence from Maura Spit in eastern Brunei where sediment transport is to the east into Brunei Bay. This change has been attributed by James (1984) to wave refraction in Brunei Bay, decreasing the effectiveness of the northeasterly waves during the NE monsoon.

2.3 TIDES

Maximum tidal range at Victoria Harbour is 1.3 m, and maximum surface tidal flows in the coastal waters are less than 1 m/sec (Admiralty Chart. No. 1844). Flows are strongest in the narrow channels off the southwestern and southeastern extremities of the island. It is the strong flows in these channels which have led to their anomalous depth, the channel southeast of Tg. Teras reaches a depth of 46 m and that north of Keramen reaches 76 m (Figure 11 - from Admiralty Chart No. 1844). All water depths in this report are given as below Chart Datum which is close to Lowest Astronomical Tides. Chart Datum is 1.2 m below Land Survey Datum on Labuan.

2.4 BATHYMETRY

The island lies at the northwestern mouth to Brunei Bay, an almost square shaped shallow embayment with a maximum depth of about 37 m, and measuring about 35 km across (Figures 10 and 11). Water enters the bay through the constricting channels to the east of Labuan, and through the channels between the islands southwest of Labuan and the Brunei mainland.

Labuan is surrounded by relatively shallow water, off the west coast the shelf flattens out at a depth of about 25 m to 30 m some 6 km offshore, and similar depths are found to the south in Brunei Bay. East Channel, to the east of the island, is generally shallower with a minimum depth of about 10 m east of Kubong Bluff. Coral reefs are common in waters down to about 5 m around the island, and offshore isolated, steep sided reefs rise above the general sea floor level, and the tops of many are exposed at low water (Figure 2).

Numerous small islands are found to the south of the Labuan, most have a bedrock core with a surround of coral reefs. These islands constrict the tidal currents leading to locally overdeepened inter-island channels. The largest of these channels is that southeast of Labuan between the island and Pulau Papan and Pulau Daat (Figure 2). This channel is some 15 km long, it has smooth steep sides, and is asymmetric in long profile with the deepest part near its southern termination. In the south (between Rancha Rancha and Pulau Papan) the floor of the channel, which reaches a maximum depth of 46 m, is rougher than the sides and surrounding sea bed. This suggests that the floor below about 30 m may be cut into older, coarser, Quaternary sediments. Channels between the smaller islands and reefs east of Palau

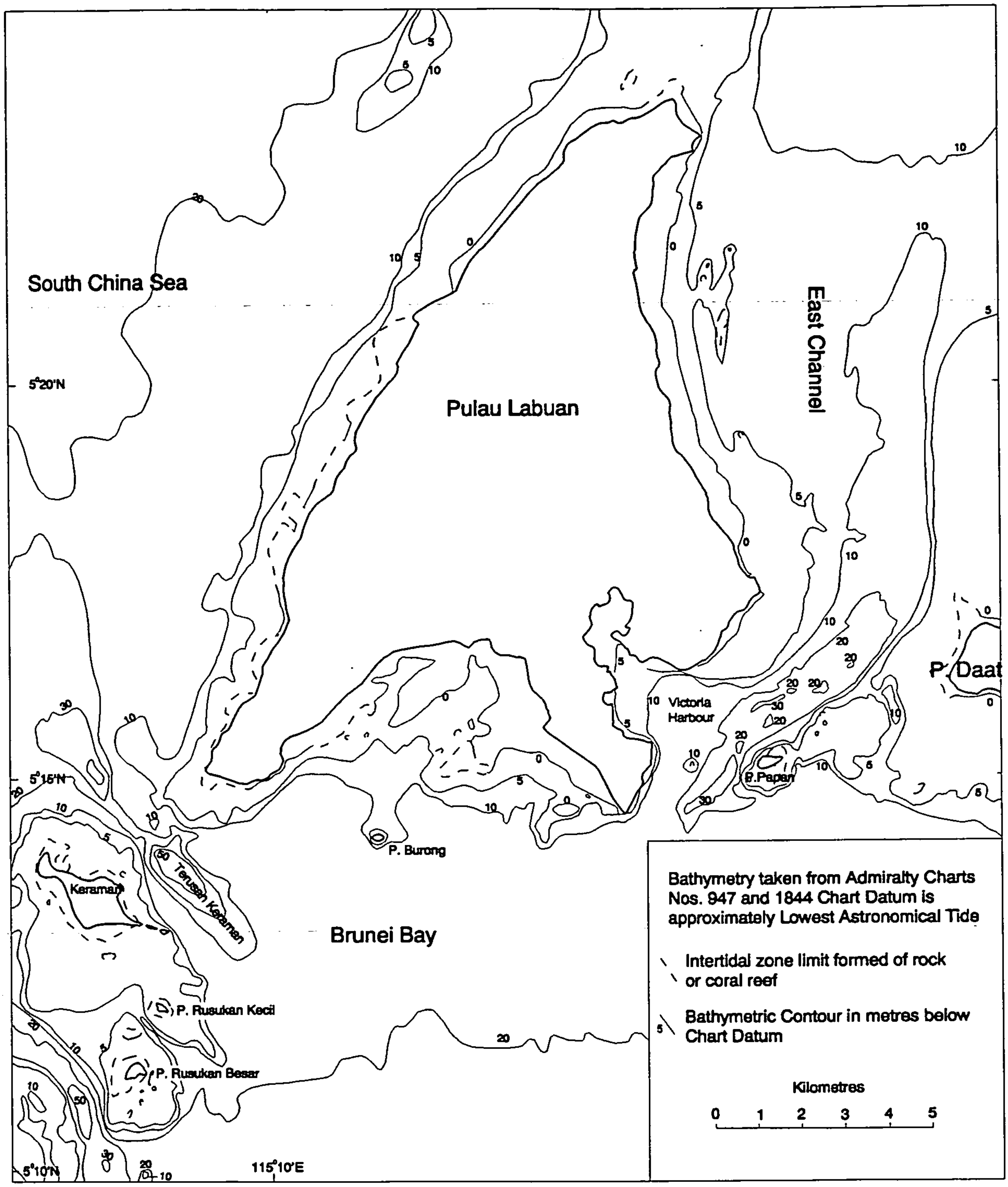
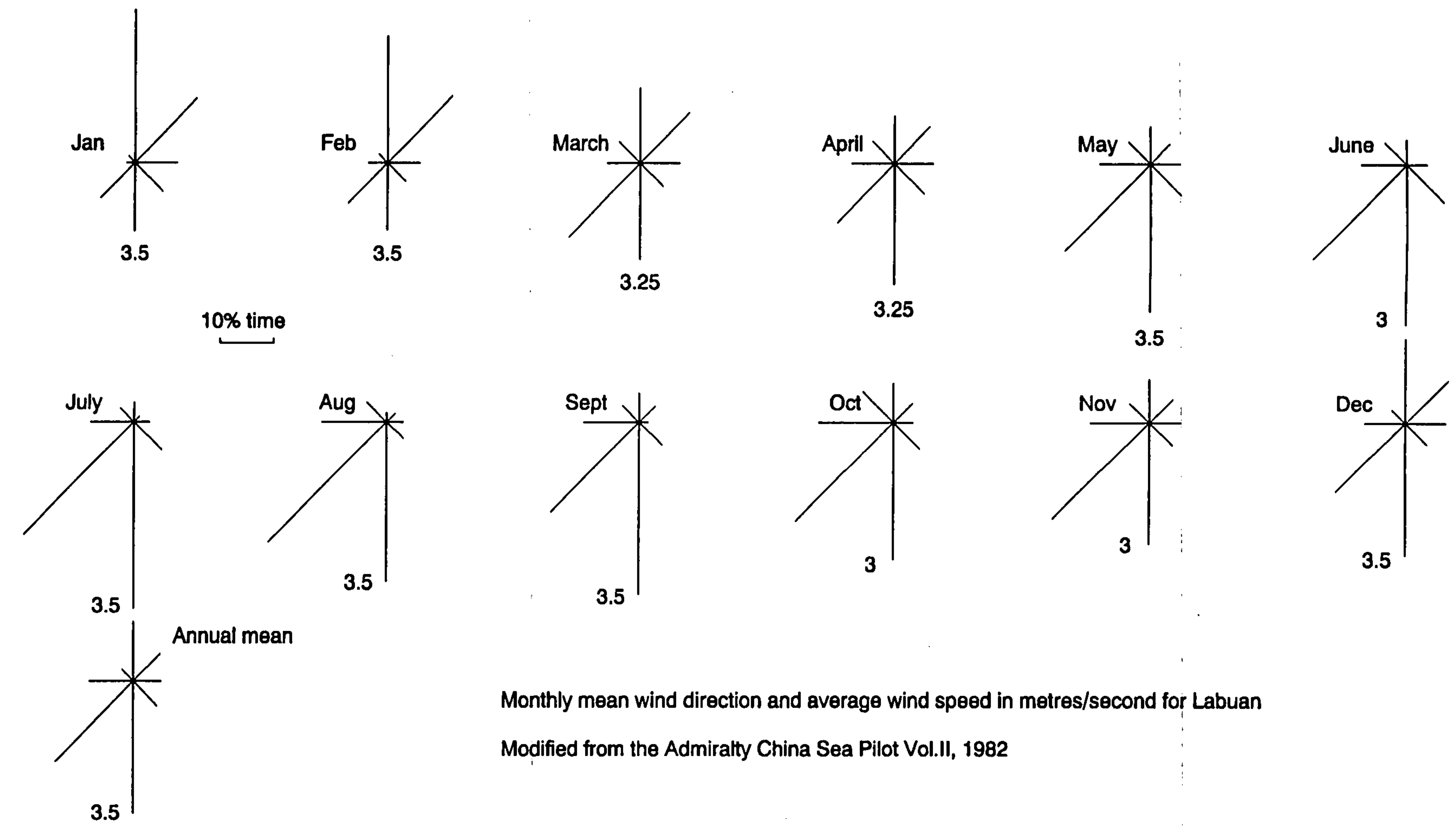


Figure 11 Bathymetry of the waters around Labaun, Malaysia



Monthly mean wind direction and average wind speed in metres/second for Labuan

Modified from the Admiralty China Sea Pilot Vol.II, 1982

Figure 12 Wind data for Labuan

Papan reach a maximum depth of 19 m. Terusan Keraman, the channel between Tg. Punei and Keraman island (Figure 11) is about 8 km long and orientated northwest-southeast. It is divided in two by a high named "Undaunted Rock". Maximum depths in the two parts of the channel are 76 m and 79 m. Similar sized channels exist to the southwest separating Pulau Papan from Barat Banks (maximum depth of 71 m) and Barat Banks and the Brunei coast (maximum depth of 136 m). These values are taken from Admiralty Chart No.1844.

The channels are the product of strong tidal currents moving in and out of Brunei Bay. They probably form part of the late Quaternary drainage system established when sea level was much lower than at present. Slow sedimentation on the continental shelf during the subsequent rise in sea level led to the infill of most of these channels, except those in areas of strong tidal currents. A shallow seismic profile run by GSM across the southern end of East Channel identified a complex multi-infill channel with a base some 120 m below sea level. The age of this channel is not known but it was probably incised at the same time as the deeper open channels mentioned above.

2.5 GEOLOGICAL SETTING OF THE ISLAND

The island is composed of well bedded, Miocene sandstone and mudstone with some conglomerate and coal (Wilson, 1964). The broad structure of the island is a NNE plunging anticline with general dips on the flanks of about 20° to 30° and locally up to 80°. The dips shown on the geological map in Wilson (1964), based on field work by Heybrek for the Shell Company in 1954, indicate that smaller scale folding may be superimposed onto the main anticline. Faults generally trend NNW-SSE though their extent is uncertain due to limited exposures on the island. Limonite-rich conglomerates form the prominent ridge crossing the northern part of the island.

Coal was mined for sixty years from the Belait Formation which forms the ridge along the northern part of the island. Up to half a million tons were produced up to 1912 when mining ceased due to flooding difficulties. A report by Powell Duffryn Company in 1947 suggested that mining could be resumed without much difficulty and that 9 million tons of sub-bituminous, non-coking coal may exist in one seam alone.

Numerous natural oil and gas seeps have been reported from the island (Figure 14) forming thin films or seeps in the intertidal zone or emerging from bedrock. Gas was noticed only in swampy or intertidal areas. Wilson (1964) reported that a 7 m deep well excavated onshore at Kubong Bluff in 1860 produced 12 gallons daily and was still flowing 19 years later; a well drilled to 137 m at S. Gangarrak in 1898 reported gas shows. A deep well drilled in 1961 off Keraman Island reached 2763 m and reported gas shows, though they were not of commercial significance. More extensive drilling in the deeper parts of the South China Sea off Labuan have proved commercially viable hydrocarbons fields (Figure 10). Lee Chai Peng (1977) reported that the "active mud spring" identified near Kg. Layang Layangan in 1963 (Wilson, 1964) could not be identified in 1977.

Some 40% of the island is formed of lowlying Holocene deposits including swamp with mangrove fringes, alluvium, "raised beach" and beach. Figure 13 showing the distribution of these units is based on a photogeological interpretation of the island by the GSM.

Sandy iron-rich sediments 1.5 to 3 m thick cover much of the island. Fitch (1953) identified three erosion surfaces on the island, the highest the *Airport Platform* at a height of 25 m, the *Hospital Platform* at 10 m and the modern platform at 3 m. Fine white sand up to 2.5 m thick cover the higher two platforms, and the lower platform, also called a raised beach, is formed of light brown to buff quartz sand with coral and shell fragments locally cemented into beach rock.

Korotky and others (1995) described, along the shores of islands off the Vietnam coast, a series of Holocene marine terraces at altitudes of between 1.5 to 6.0 m above average sea level (a.s.l.). Radiocarbon dating of coral and shell showed that the highest of these terraces were formed about 5060 - 6800 yr B.P. and the lowest to 900 - 1200 yr B.P. The sea level during this period was considered to have risen by between 0.5 to 3 m above the modern level. Geyh, and others (1979) reported sea level in the Straits of Malacca some 2 m to 5 m above the present level between 500 years to 7000 years ago (Mid-Holocene); and Tija and others (1977) reported extensive areas in the southern part of the South China Sea with Mid-Holocene highstands of similar magnitudes.

The raised beach platform along the coast of Labuan (see below) may have been deposited during the Mid Holocene high stands, though Labuan is part of a neotectonically active continental margin (Hazebroek and Tan, 1993), unlike the peninsula Malaysia which forms part of a more stable tectonic block. Tija (1996, Figure 1) suggested vertical movements of 6.5 mm/year along the northwest Sabah coast, in contrast to a value of 0.23 mm/year for the western coast of Kalimantan, which is part of the more stable Sundaland region.

2.6 COASTAL GEOLOGY OF THE ISLAND

The western, eastern and southern coasts of the island present distinctive morphologies (Figures 13 and 14). The western coast is open to the South China Sea and parallel to the monsoonal wind directions; The southern coast is largely protected from the monsoonal winds and the eastern coast is open to the northeastern monsoon but protected from the southwestern monsoon.

2.6.1 West Coast

The western coast of the island is predominantly a sandy beach backed by a "raised beach" system generally about 200 to 300 m wide though locally up to 800 m wide (Figure 13 and Photo 26). Such beaches are absent from the northern and southernmost extremities of this coast, and also from around Tg. Layang-Layangan where there is a rocky foreshore (Photo 27).

The western coast of the island has an intertidal zone up to about 150 m wide and the sea bed slopes uniformly to the northwest to attain a depth of about 19 m some 3 km offshore. Coral reefs introduce some irregularity to the bathymetry of the shallower parts of this zone. The sea bed slope is steeper along this coast than along the eastern and southern coasts. This is probably a function of the higher wave energy on this coast compared to that experienced by the more protected eastern and southern coasts.

The general form of the beach varies along the coast from a wide beach with an uniform

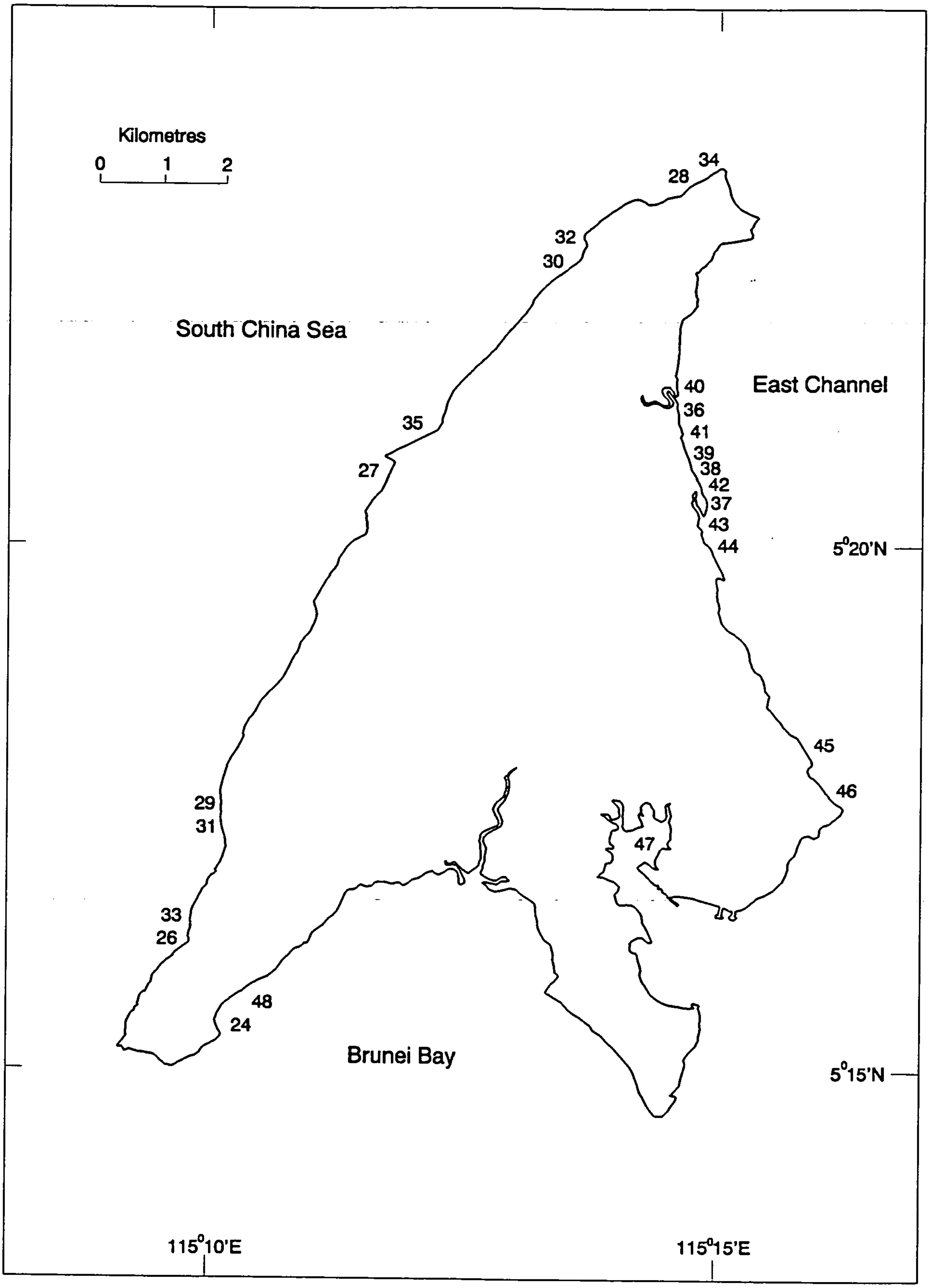


Figure 16 Location of photographs from the coast of Labuan included in this report

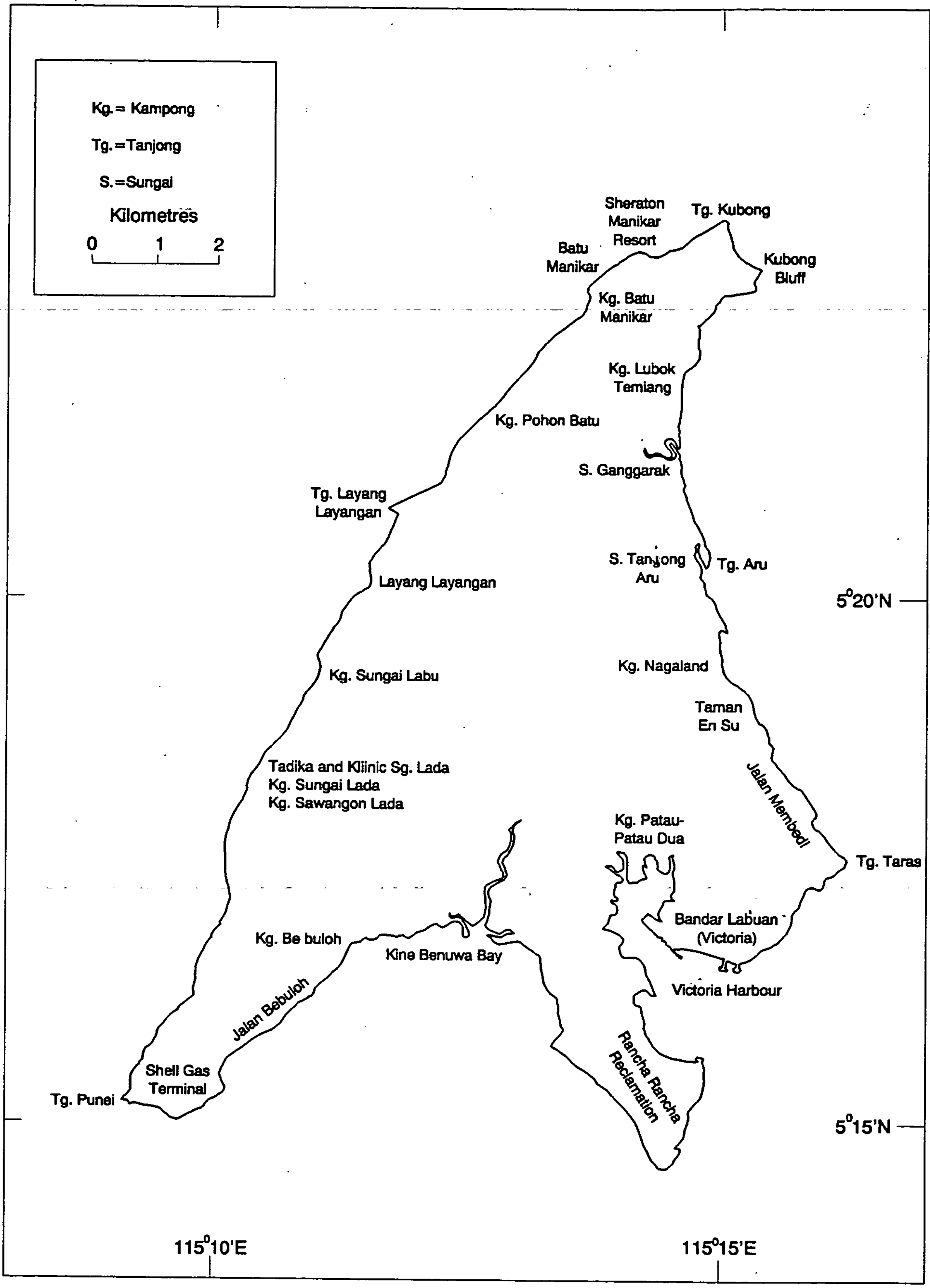


Figure 15 Location of Labuan place names used in this report

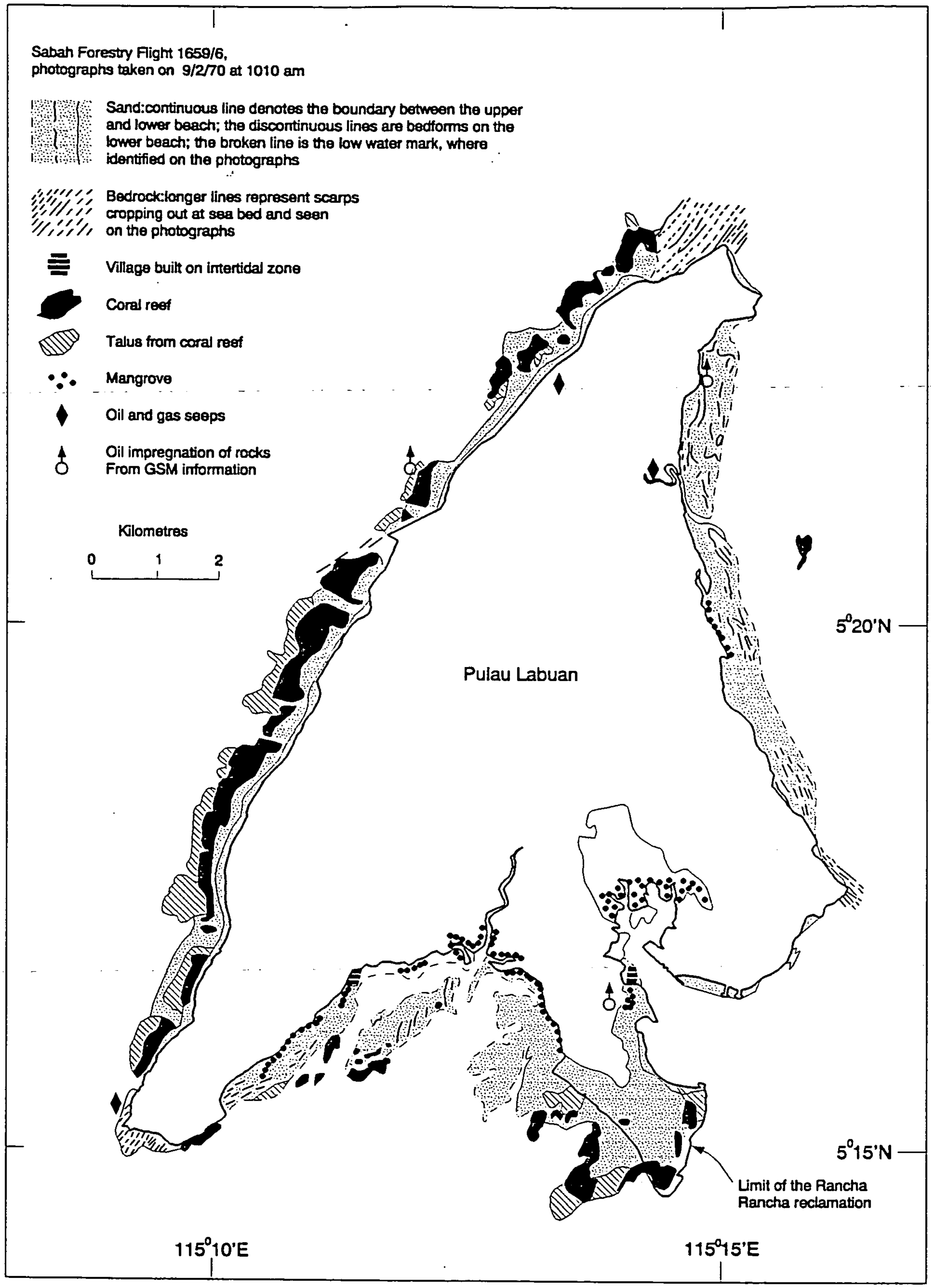


Figure 14 Airphoto interpretation of the intertidal zone of Labuan

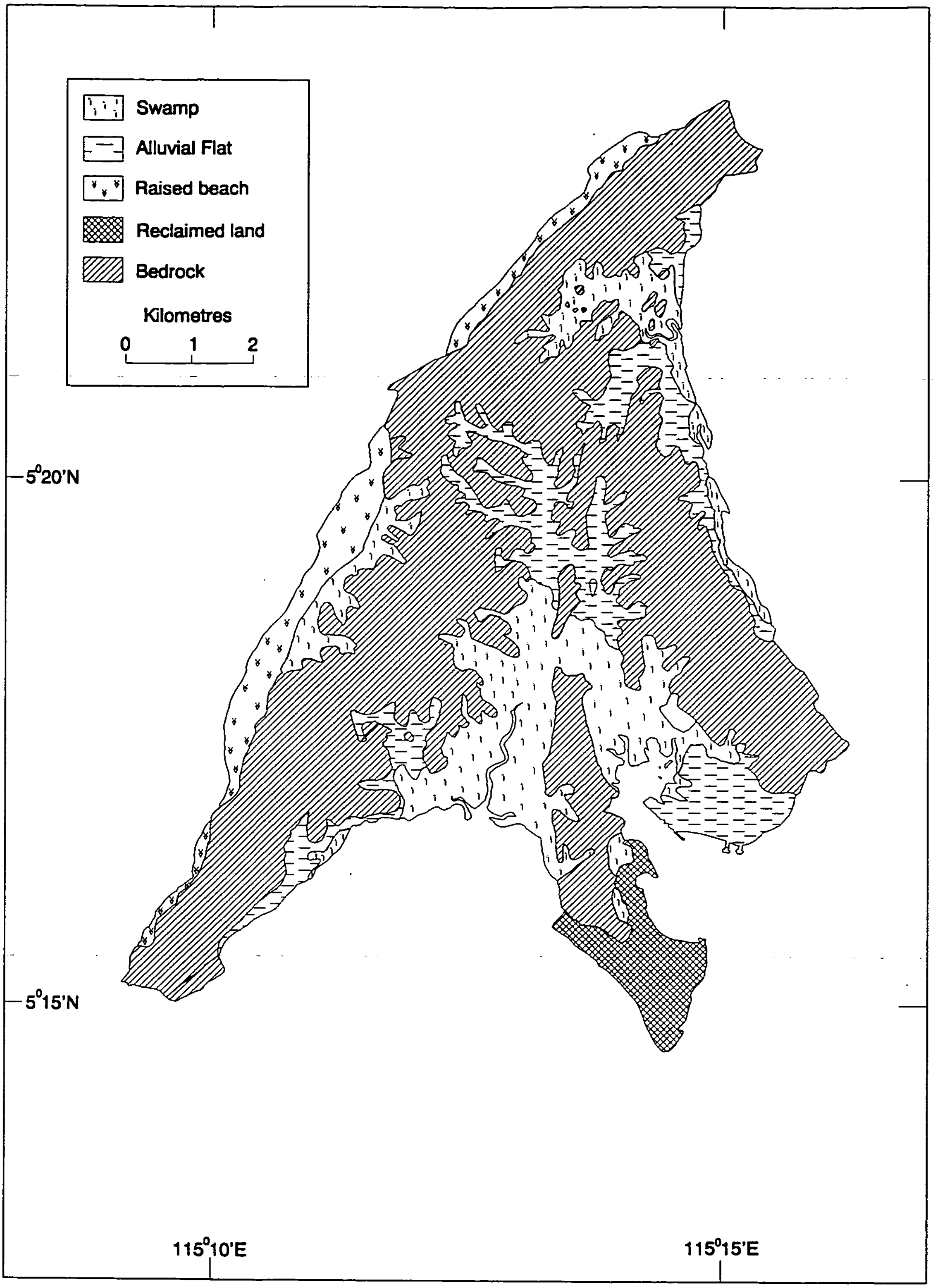


Figure 13 Geomorphic map of Labuan. Based on a photogeological interpretation by the Geological Survey of Malaysia

gentle slope, to a beach with a distinct, upper, narrow section with a steep gradient, and a lower section with a gentler gradient. Locally a low berm is developed about half way down the lower beach. The intertidal zone is about 150 m wide at Kg. Layang Layangan and Kg. Pohon Batu and is strewn with seaweed. Locally large logs are found along the coast (Photo 28). Most are anchored in the sand along the high water mark, though some are stranded on the intertidal flat. Both cut logs and uncut uprooted tree stumps are found. The build-up of sand around the logs, and their obvious antiquity, indicates that they play an important part in limiting erosion of the upper beach. They should not be removed to enhance the aesthetic appearance of the beach.

The beaches are formed of well sorted, cream coloured, medium- to fine-grained quartz sand with a moderate coral content (Photo 29). Rounded, gravel-sized coral fragments are locally common across all the intertidal area. The coarsest sand occurs on the steeper upper beach, the lower beach in these areas is composed of finer grained, rippled sand. Locally extensive patches of displaced sea weed covers the beach and the resort at Batu Manikar uses a tractor to clear the beach of weed. Bioturbation of the lower beach is locally extensive with much reworking by burrowing crabs.

The precise altitude of the "raised beach" has not been measured relative to any levelled mark, but lies about a metre above the modern highest tide line (Photo 30). Wilson (1964, p 82) described the *Modern Platform* as being about "10 feet high", though this is not referred to any precise level. The beach may have formed during a higher Holocene sea level or it may be a consequence of sediment accretion when sea level was at, or close to its present level. The "raised beach" is covered by casuarina trees and coconut palms. Locally the trees lining the top of the modern beach are toppling over, indicating long term erosion (Photo 31). Mangrove is almost absent from the west coast but for a minor development in the bay at Tg. Layang Layangan.

A National Coastal Erosion Survey (1985) identified significant erosion (likely to have socio-economic losses over the next 10 to 20 years) along about a kilometre of coast at Kg. Sawangan Lada and Kg. Layang Layangan (Figure 15). Housing was affected at the former and both housing and agriculture is affected at the latter. Acceptable erosion (likely to result in no social or economic losses over the next 10 to 20 years) was reported along the coast at Tg. Punei.

An examination of the coastal zone in February 1994 identified a range of features indicating natural erosion of the coast; these included sporadic toppled and toppling trees along the beach top, and the crenulated form of the landward margin of the beach top. Erosion extends landward between the trees whilst their roots arrest beach retreat. Erosion of the "raised beach" is most pronounced where the modern beach displays the steep, upper beach and gentler, lower beach morphology.

Man-made defences to limit coastal erosion have been built near S. Timbaran and south of Tadika (Figure 15). At both sites the defences have become necessary because a road has been built along the coast where no natural protection to retreat is afforded by trees. At the former site the low wirebasket wall was covered in February 1994 by vegetation and fronted by large logs (Photo 33). This suggests that the area is now stable. An extensive sea wall system was built in 1990 at Tadika. Erosion has cut the coast back about 2 m at the southern end of the wall, but along its northern margin the level of the beach has risen to cover the lower part of the wall.

Northeast of Batu Manikar, along a kilometre length of coast north of Tg. Layang Layangan, and along the coast for about a kilometre north of Tg. Punei, the raised beach is absent and the narrow beach is backed by cliffs of bedrock. At these locations the cliffs, formed predominantly of mudstone and siltstone, are being eroded to leave a wide intertidal rock platform. Small pocket beaches of sandy gravel locally front the cliffs, and an irregular layer of boulders and pebbles covers the intertidal platform (Photo 34).

At low tide a bedrock intertidal platform is exposed in the small bay east of, and enclosed by, Tg. Layang Layangan. The northeastern, inner part of the bay has a narrow sandy beach near the high water line but the intertidal zone is generally composed of bedrock with a thin, variable mud veneer (Photo 27). The sparsity of sediment in the bay is a result of the rocky ledges at its mouth restricting the entry of sediment, which is predicted to move along this coast from northeast to southwest (National Coastal Erosion Survey, 1985).

Fringing coral reefs are found off the west coast of Labuan (Figure 14). The reefs consist of shallow, living coral interspersed between coral rubble and sandy areas (Photo 35). The reefs are sites of coral sand production, and the sandy channels between the reefs may be conduits transferring this sand into both deeper or shallower water.The reefs are presently in a poor condition and weed covered.

The extent of the fringing coral reefs on Figure 14 was derived from aerial photographs and Section 3 of this report deals with the use of Landsat satellite imagery of Labuan in delimiting such reefs.

No major morphological indicators of southwestward moving sediment are found along this western coast. The absence of sand in the intertidal zone and off the northeastern sector of the coast north of Batu Maniakar indicates that sand cannot be moving onto the coast from northeast of the island. Substantial sand for feeding the beaches may have been derived from the offshore coral reefs. The destruction of much of the offshore fringing coral reefs and their covering by weed over the last two decades must have reduced the offshore sediment supply to the beach and this may account for erosion along the present coastline.

2.6.2 East coast

The east coast of the island is protected from the southwest but is open to the northeast monsoon winds. Thus, longshore drift on this coast is from north to south. The "raised beach" typical of the western coast of the island is not as extensive on the east coast which is generally backed by a narrow zone of mangrove swamp (Vijayan, 1992) fronted by a raised beach some tens of metres wide (Figure 13). At many locations the swamp has been drained resulting in an imperceptible passage from the raised beach to the landward rise in slope marking the outcrop of bedrock. The precise height of the raised beach relative to a known datum was not measured. Photo 30 shows the top of the raised beach less than a metre above the highwater mark, and Chow Weng Sum (1992) quoted a height of 1.5 m for the raised beach.

Most of the east coast of Labuan is formed of an open, slightly concave bay enclosed by the headlands of Kubong Bluff and Tg. Taras (Figure 11). The short length of coast north of Kubong Bluff to Tg. Kubong marks the eastern limit of the ridge forming the northern part of the island, and is backed by cliffs up to 15 m high. Seaward of the cliffs is a wave cut platform covered by pebbles and boulders, and mobile sediment is limited along this part of the coast to small pocket beaches (Photo 34). The wave cut platform extends offshore northeast of Tg. Kubong for at least 3.5 km, to produce an irregular sea floor with a locally areas, probably of rock, shallower than 4 m (Figure 19). Modern erosion of this rock platform is minimal and the morphology of the area shows that little sediment is being transported towards the northeast coast of Labuan from offshore.

The bay south of Kubong Bluff to Tg. Taras has a flat intertidal zone some 500 m wide, a steeper slope from 0 m to 4 m (below CD), and a flatter seaward inclination, such that in the northern part of the bay the 10 m isobath is over 5 km from the coast (Figure 11).

A series of coral reefs lie about 2 km offshore, their tops break surface during the lowest tides, and the surrounding sea bed in their vicinity is at between 4 to 6 m. The sea bed seaward of the reefs is formed of mud with less than 25% sand content (Vijayan and others, 1992). Landward the seabed sediments are sandier.

The intertidal zone within the bay is divisible into a steep, narrow upper beach formed of medium- to coarse-grained quartz and coral-rich sand, and a flatter, lower beach formed of intensely bioturbated, rippled, muddier sand (Photos 37 and 42). The ripples are wave generated, and are orientated nearly parallel to the coast. General bedform distribution on the flats was not examined during the visits as the tide was moderately high when the coast was examined. Drilling in the intertidal zone has proved fine- to medium-grained sand some 2 to 5 m thick, locally containing beach rock, overlying soft clay up to 4 m thick, and passing down into bedrock (Chow Weng Sum, 1992).

The eastern coast displays rapid variations in accretional and erosional sections along its length. Typical of the eroding coast is the 2 km section between S.Ganggarak and the north of Tg. Aru. Along parts of this coast fallen coconut palms (Photo 28), areas of eroded mangrove trees (Photo 29) and a wrecked landing stage indicate retreat of the coast by about 1 metre a year over the past ten years. Local fishermen confirmed that the erosion had proceeded at this pace for over 20 years. The mature mangrove trees along this part of the coast north of Tg. Aru are suffering rapid erosion leaving a 10 m to 20 m wide swathe of truncated tree stumps, roots and soil. South of S. Ganggarak, an electricity substation at the landward end of the submarine electricity cable from Sabah, is protected by a wirebasket wall (Photo 30). A similar structure has been placed to protect a recently constructed house about a kilometre to the south (Photo 31).

The cause of the erosion is not obvious. Beachrock (Bathhurst, 1977, 367p; and Carter, 1991) occurs at these locations (Photo 31 and 32) within the upper beach, and in the higher parts of the lower beach. Its formation typically occurs in intertidal and supratidal zones where fluctuations in the water content of the sand lead to the deposition of a calcite cement. The occurrence of beachrock creates a section of beach which is more resistant to erosion and reduces the volume of eroded sediment moved alongshore. Thus erosion of the coast may be increased down drift of the beachrock areas. Photo 26 shows that the beachrock is undergoing slow erosion by undercutting to leave large tumbled blocks. Photo 32 shows scattered beachrock cropping out in the upper part of the lower beach.

The sand released by the erosion of the coast moves southward to form the southward extending Tg. Aru spit (Photo 33). The spit is extending southwards over the lower beach. The boundary between the sand forming the spit and the lower beach is abrupt, an indication of the efficient sorting by waves of the beach sediments. The lower part of the spit is formed of brown to buff, coarse-grained sand and coral fragments, whilst the upper part is formed of white to cream-coloured, fine- to medium-grained sand.

South of the end of the spit mangrove trees and roots are growing on the accreting lower beach (Photo 34). During the examination of the coast in February 1994, S. Aru was barely more than a stream some 10 cm deep and about 10 m wide. Rainfall during February is less than a third of that in the autumn months (Admiralty Pilot, 1992) and the flow in the river would probably be much greater during the wetter season. The river is not a major source of sediment to the coast, the sediment trapped in the spit is derived primarily from the coast to the north, and the coast a few hundred metres south of the spit reverts to an erosional state.

Admiralty Chart No. 1844 shows southward extending spits also formed at the mouths of S. Ganggarak and S. Nagaland (Figure 19). This confirms the net southward coastal movement along the coast in the bay.

The beach at the southern end of the bay (Jalan Membedai) displays a single gentle gradient and is formed of well-sorted, medium- to fine-grained sand (Photo 20). The form of the beach and the well established casuarina tree cover on the raised beach to landward, show that the coast in this area is slowly accreting, presumably utilising sediment derived from the northern part of the bay.

Immediately south of Jalan Membedai the form of the coast changes, the offshore gradient steepens and the coast becomes cliffed with only a narrow sandy beach at the foot of the cliff. The cemetery on the cliff top at Tg. Taras is presently being cut back by cliff erosion. Photo 46 shows a cylindrical grave headstone within a metre of the cliff edge with the eroding cliffs beyond. Some of the surrounding graves date from the 1930s suggesting that many metres of cliff have been removed since this time, but it is difficult to make a more precise estimate of the cliff retreat rate.

2.6.3. South coast

The south coast of Labuan is formed of two bays, fed by the S. King Benua to the west, and the S. Batu Arang to the east (Figure 11). The headland of Rancha Rancha with its southward extension of reclaimed land separates the two bays. Victoria, the main town of Labuan, lies on the eastern shores of the eastern bay and the new oil-industry fabrication yards and other industries line the western shores of this bay. The outer shores of Victoria Harbour are therefore almost all man-made though the inner part of the harbour, north and west of the town is formed of mangrove swamps infiltrated by shanty dwellings (Photo 37).

The waters of the bay fed by S. King Benua are very shallow. Admiralty Chart No.1844 shows the intertidal zone along the western coast of the bay to be about 400 m wide and locally on the east coast up to 3 km wide (Figure 11). Coral reefs and mud underlie the shallow subtidal waters, and the 10 m isobath rarely lies landward of a line from Tg. Punei to the southern limit of the Rancha Rancha reclamation. Sediments in the bay are primarily mottled yellow-brown to pale grey clay, locally over 4 m thick.

The eastern bay occupied by Victoria Harbour is significantly deeper than the bay to the west due to its location northeast of the deep tidal channel west of Pulau Papan. No dredging is necessary in the harbour to keep a depth of over 9 m at the edge of the largest wharf. This indicates that little mud is brought down by rivers on Labuan, or transported into the harbour from Brunei Bay.

The reclaim area of Rancha Rancha is composed of coral debris obtained form the many small coral islands south of Labuan.

The south coast is protected from the northeast monsoon by land, and largely from the southwest monsoon by Tg. Punie headland, offshore islands, and the shallow water to the south of Labuan.

The shoreline of the western bay, east from S. Kina Benua to Rancha Rancha is a generally muddy beach backed by mangrove. A.I & Associates (1993) reported 763 hectares of mangrove around the mouth of S. Kina Benuwa. West of the rivermouth the shoreline is similar but with outcrops of bedrock within the intertidal zone. Some of the pocket beaches from the area display a morphology similar to that on the east coast of the island (Photo 38) with a narrow, steep upper beach of coarse-grained, poorly-sorted sand at the base, passing upward into well-sorted medium- to fine-grained sand at the top. The lower part of the beach has a very low gradient and at one locality the sea bed is only 0.5 m below LAT some 1.2 km from shore. The beach is formed of muddy, poorly-sorted, coral-rich sand, and is heavily bioturbated by grazing gastropods and crabs. Mangrove trees with associated areas of profuse vertical root development occur locally in the intertidal zone. This vegetation and the form of the beach indicates that the coastline is slowly accreting.

Aerial photographs taken in 1970 show coral reefs in the bay (Figure 14) and some of these have been extensively dredged to provide onshore fill material.

Kg. Bebuloh is a stilt village built out onto the intertidal zone of this coast and first established some thirty years ago (Figure 14). The height of the intertidal beach above of the floors of the oldest houses in the village, those nearest the shore, shows that limited sedimentation has occurred along this coast over the past thirty years.

2.7 MORPHOLOGY OF LABUAN BEACHES

The coast around Labuan is one characterised by a large tidal range (1.3 m) compared with the average wave height, which is estimated from the average wind speed (3.5 m/sec) and fetch to be at less than a metre.

Komar (1978 p. 297) described such beaches as being "characterised by a relatively steep beach face terminated abruptly at its base by a wide low-tide terrace. Generally the high-tide beach face is composed of sediments coarser than that of the terrace.... In addition the low-tide terrace are characterised by poorly-sorted fine-grained sediments, well-formed and complex ripple marks and more abundant infauna." This is an excellent description of the beaches shown in Photos 27, 43 and 48. Seaward of the terrace Komar (1978) described a low-tide beach whose slope is somewhat greater than the terrace. The steeper profile off the east coast of Labuan just below low water mark (between isobaths 0 m to 4 m on Figure 18) may be such a feature. Thus the two steeper sections of beach are due to the brief still stand in water level at high and low tide which result in a concentration of wave energy at these levels.

The wave energy is probably less along those sections of coast where the two-fold gradient in beach profile is replaced by a single gentler gradient. These variations in wave energy are probably controlled by the offshore coral reefs which act as breakwaters. The precise sections of coast protected by the reefs depend on the dominant direction of the waves, which on the east coast is from the northeast. The situation may be more complex as shown by absence of a clear relationship between the areas of erosion and accretion, and the position of the offshore reefs.

2.8 HISTORIC BATHYMETRIC CHANGES

Historic land maps and bathymetric charts provide a means of assessing changes in the position of the coastline through time. Examination of historic maps and charts to the Malaysian coast is not a new approach. Nossin (1964) used historic charts dating back to the 1726 to date accretion on the east coast of Malaysia north of Pahang. Wong (1981) compared charts to assess seasonal beach changes due to changing monsoon conditions, and Kamaludin (1993) used air photographs to evaluate changes in mangrove shorelines at Kuala Kurau, Peninsula Malaysia.

It has not been possible during this project to examine in detail a range of historic aerial photographs of the coastline of Labuan. However, a series of historic charts were available covering the last 150 years. An examination of data over this time frame is essential to put into perspective the rates of coastal change deduced from a field examination. The historic charts were provided by The Hydrographic Office, Ministry of Defence, United Kingdom who had detailed charts of the Labuan coast collected in 1844, 1901 and 1966. The bathymetry on the charts was contoured to a common datum and the coastline identified. A digital cartographic technique was then used to reduce the maps to the same scale and overcome distortion due to differences in map projections and paper stretching. The technique involved fitting three identified points on each coastline to their modern grid reference and reproducing each map with the points in the correct location.

The topographic map of the island was not available for digitisation in the UK so the coastline for the island was taken from the 1:25 000 scale road map bought in Labuan.

2.8.1 The 1844 survey

The accuracy of the 1844 Mouth of the Borneo River Survey by Sir Edward Belcher (L5662) is good when compared with later surveys, and the excellent fit of the coast suggests that the changes mentioned below are real, though there may be a question regarding their magnitudes.

The 1844 survey showed the east coast of the island with an irregular margin suggesting A more extensive development of mangrove than at present. The general fit of the coast compared with later maps is remarkably good but there are discrepancy compared with the modern coastline (Figure 17).

The spits at the mouth of S. Ganggarak and at Tg. Aru are missing from the 1844 map and seaward accretion of about 200 m is suggested in this area. Erosion of up to 400 m may have occurred south of S. Nagaland since 1844 and the minor kink in the coast about 1.5 km northwest of Tg. Taras is also missing from this early chart.

The south coast of the island is depicted as having an indented irregular coastline at the mouth of S. Kina Benuwa. The coast here is up to 500 m seaward of its modern position. Retreat of the coast since 1844 by about 300 m is suggested northeast of Tg. Kiamsam (Figure 16). Both of these changes may be due to landward retreat of mangroves forest fringing the coast.

On the west coast the only area of significant difference is at Tadika where up to 400 m of erosion is indicated since the 1844 map was drawn. No ornamentation suggesting mangrove is shown on this coast. There is a difference in the alignment of the coast between the 1844 and the present day northeast of Tg. Layang Layangan but this may be due to inaccuracy of the older map.

2.8.2 The 1901 Labuan East Channel Survey

This survey covers the east coast of Labuan from Tg. Kubong (Bethune Head) in the north to Tg. Taras (Collier Head) in the south. Comparison of the 1901 survey with the 1966 coastline confirms the field evidence that the coast has areas of both erosion and accretion (Figure 18).

Southward accretion of about 720 m has occurred since 1901 of the Tg. Aru spit. In the 1901 survey an area for about 500 m west of the spit is shown as a mangrove swamp and extensive mangrove persists in this area to this day. The mouth of the S. Ganggarak has moved south by some 200 m since 1901 due to the development of the spit which is not shown on the 1901 survey. Seaward accretion between 1901 and 1966, with a maximum width of 200 m, is identified for about a kilometre south of S. Kerupang. Erosion measuring locally over 100 m has been identified elsewhere along this coast.

The low water mark is almost coincident between the 1901 and 1966 surveys but the former shows well defined, straight, river courses crossing the intertidal zone which were not identified in by the 1966 surveyors, nor on the 1970 aerial photographs (Figure 14). The position and form of the offshore coral reefs are unchanged between the two surveys.

2.8.3 The 1966 Bethune Head to Victoria Harbour survey

This is the most detailed bathymetric survey available for the east coast of Labuan (Figure 19) and the coastal detail was constructed using air photographs. Points to note are the asymmetry of the northern part of the East Channel with the steeper eastern and gentler western slope; the rugged rocky? seabed north of Tg. Kubong; the string of coral reefs offshore whose crests rise to low tide level; and the shallow waters east of northern Labuan and the deep channel southeast of Tg.Taras.

This survey is sufficiently detailed and well constrained to be used, with modern data to assess long term bathymetric changes along the eastern coast of the island.

2.8.4 Comparison of historic bathymetric charts with modern field evidence

Figure 201 indicates the variation in the location and magnitude of erosion and accretion along this coast between 1901 and 1966. The surveys show minimal change in the bathymetric contours. Beach change is best delimited by changes in the position of the coastline. Both the 1844 to 1987 (Figure 17) and 1901 to 1966 (Figure 20) comparisons show that the coast of the island has areas of both erosion and accretion, and that these changes have been underway for at least 150 years. The dominant process is erosion with accretion (of the eroded material) focused on a number of spits. The accretion of Tg. Rancha Rancha and at Victoria shown on Figure 17 is man-made.

The 1844-1987 comparison is probably not sufficiently accurate to use as a guide to erosion rates but the 1901-1966 comparison is considered reliable. Tg. Aru spit is moving south at about 11 m/year and the erosion at S. Dallah to the south is up to 2/m year. These figures bear out the field observations. Erosion is shown on Figure 20 as continuing to the south towards Tg. Taras but the field evidence here is that the modern beach is accreting. The local erosion into mangrove and coconut palms shows that the locus of erosion can change with time.

The predominant historic evidence for erosion along this east coast is a clear guide that any man-made change to the coastal sediment budget and long shore drift may have erosional effects and should be carried out with care.

2.8.5 Conclusion

Historic bathymetric charts can provide useful information on long term coastal change, especially with regard to changes in the position of the coast. The greater the accuracy of the baseline topographic map and the bathymetric surveys the better the estimate of rates of change.

If the Geological Survey of Malaysia want to obtain more accurate measurements of the rates of coastal change then air photographs, preferably in colour, should be run across the Labuan coast and compared photogrametrically with those collected in 1970.

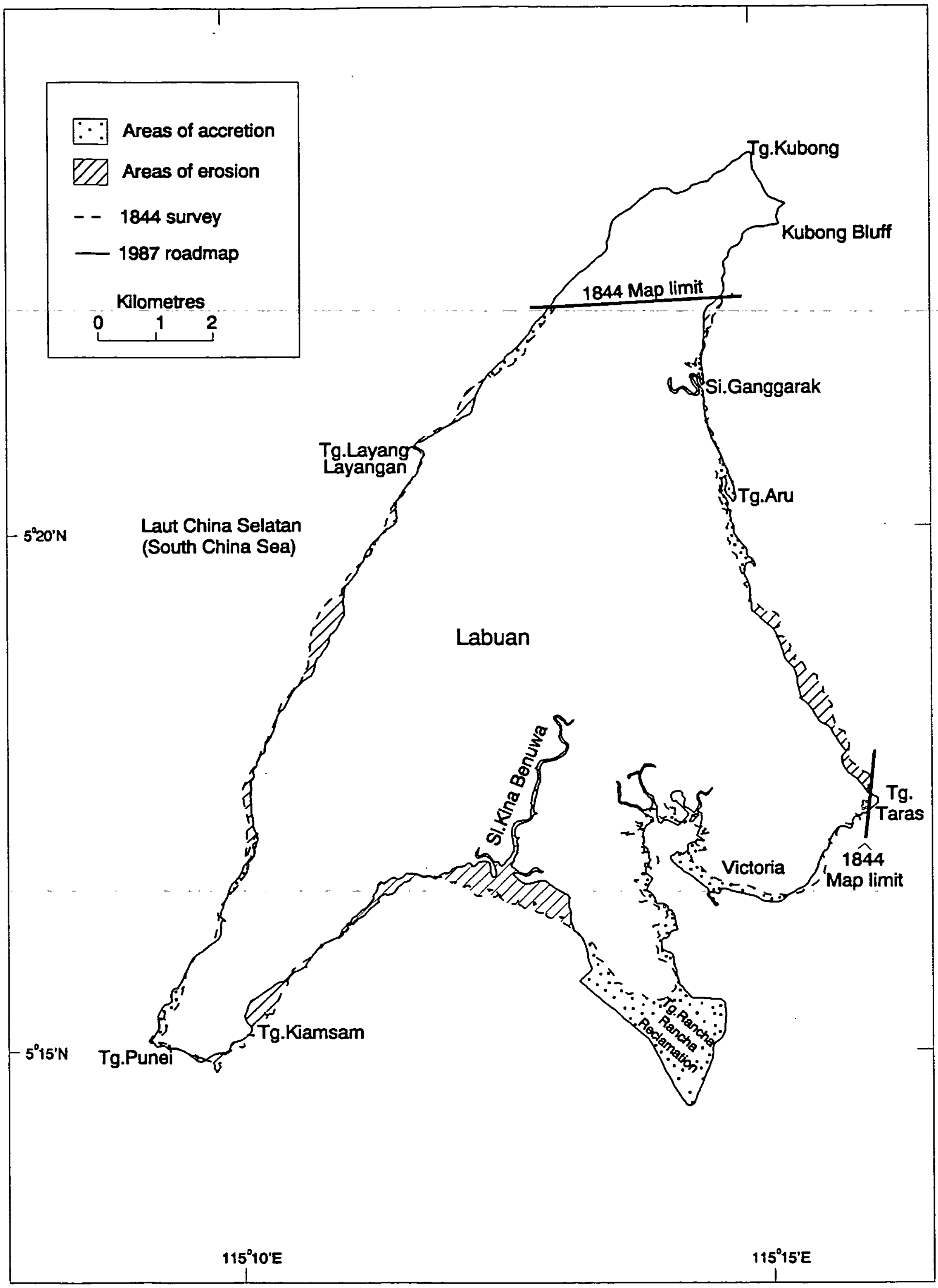


Figure 17 Comparison of the modern coast line of Labuan with that taken from the 1844 bathymetric survey

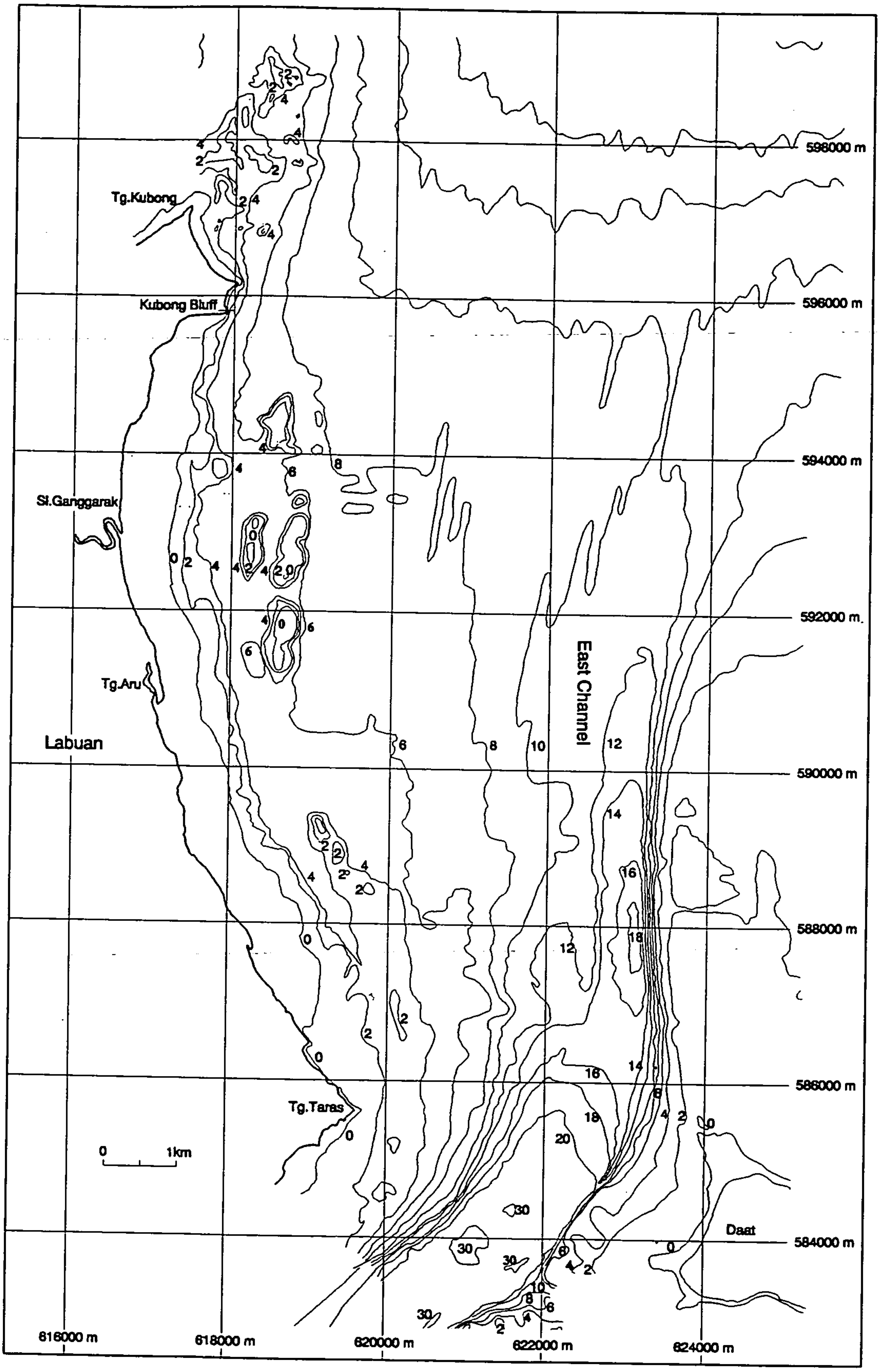


Figure 19 Bathymetry of East Channel from the 1966 Hydrographic Office Survey. Chart Datum - Lowest Astronomical Tide.

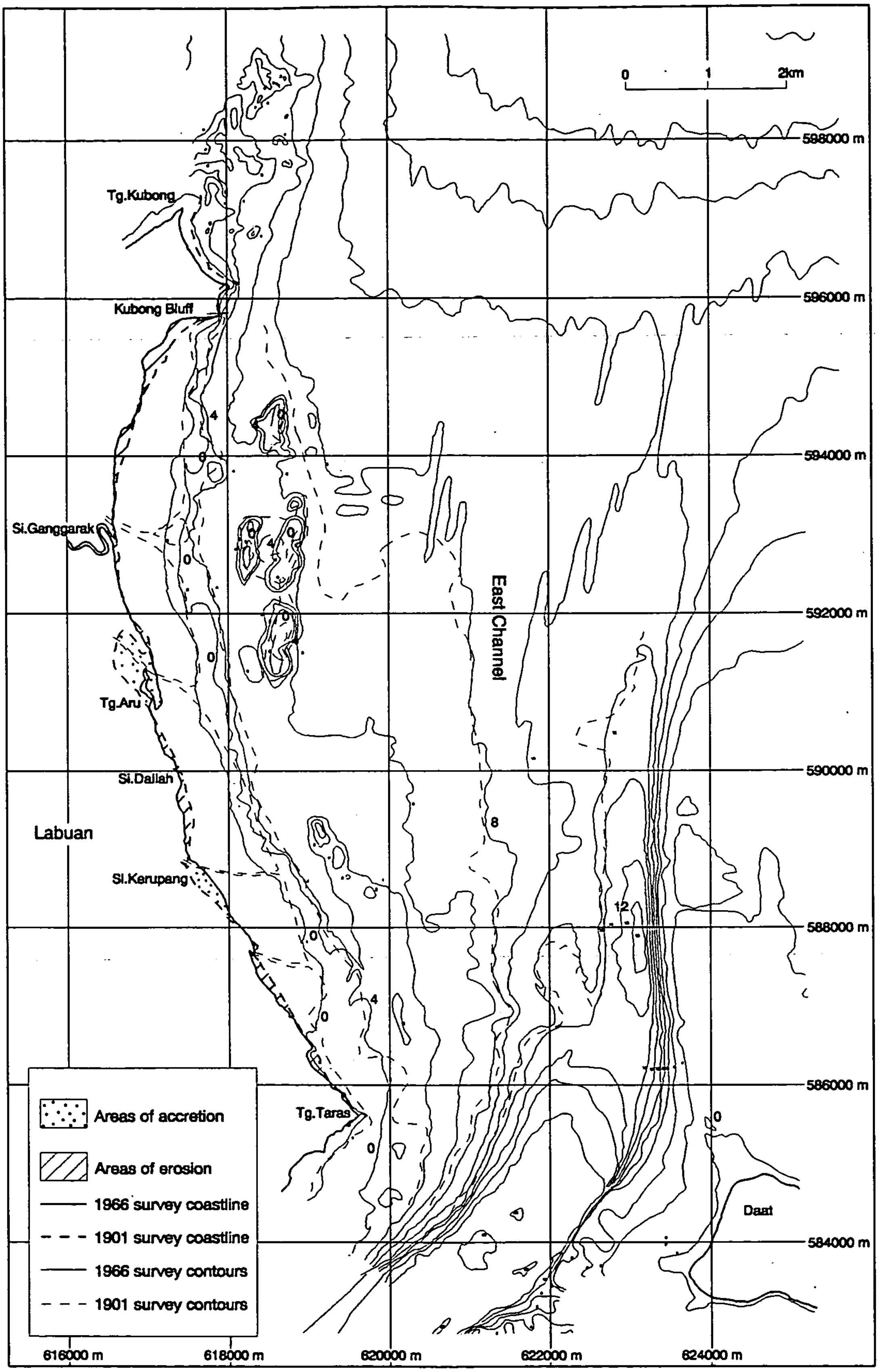


Figure 20 Comparison of the coastline of East Channel between the 1901 survey and 1966 survey.

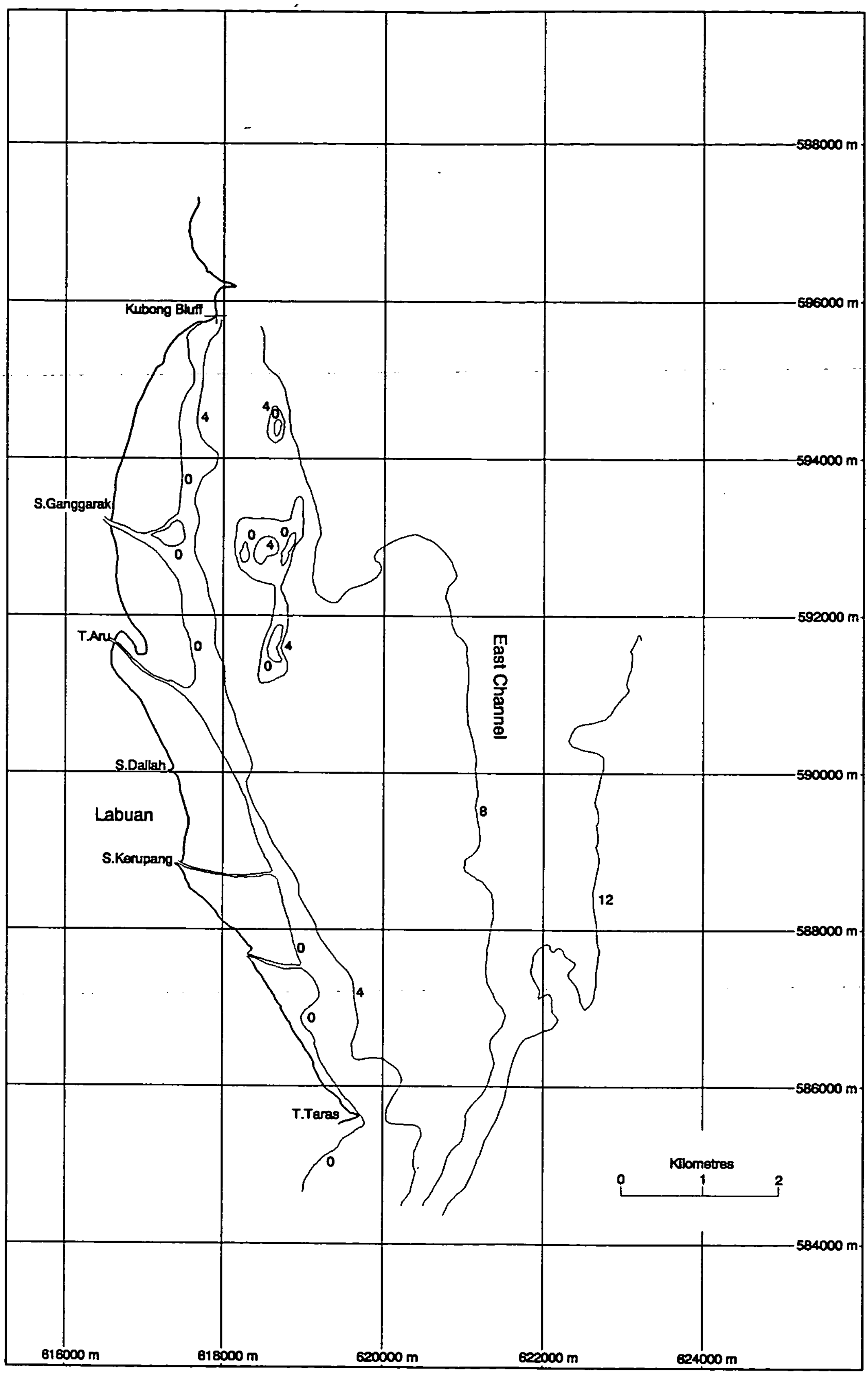


Figure 18 The coastline of East Channel from the 1901 survey.

3. REMOTE SENSING

The aim of a geoscientific database for the coastal zone is to aid the addressing of scientific questions on the geology of the zone, and the natural processes which affect it. At some stage morphological and environmental mapping of the zone becomes necessary along with broad assessments of the quality of the nearshore waters. Field mapping and air photographs provide the best detailed information, but for a wider overview the most rapid assessment may be obtained from images taken from satellites. The present suite of standard satellite imagery (Landsat and SPOT) acquire digital information at a number of specific wavelengths (or bands) and are commonly supplied on computer tapes rather than as photographs. Computer processing these data allows more information to be extracted from the scene than is possible from photographs.

A tape of a Landsat scene of Labuan and adjacent western Sabah coast was provided to BGS by GSM in order to assess the contribution of this type of data to coastal zone mapping. The Landsat 5 Thematic Mapper (TM) image (Path/Row 118/56 collected on 14 June 1991: Figure 21a) provided information on seven wavelength bands, and a combination of these have been used to create the image. At the time the image was collected the tide was high in the area, and rainfall in June is transitional between the drier January-March period, and the wetter September-November period.

The scene in Figure 21a covers an area of 101 by 73 kilometres. The pixel size of the Landsat system is about 30 m, which at 1:100 000 scale (the scale of Figures 21 to 24) measures 0.3 mm. The resolution of the scene is of this order although smaller bright objects such as ships off Victoria Harbour and possibly aircraft on the runway at Labuan airport (Figure 22a) can be discerned.

As the tide was high when the scene was collected the image provides limited additional information on the coastal zone of Labuan beyond that identified from the field and air photographs. However, it does provide a wealth of information on the surrounding waters and coasts, not visited during the project, which enables the coastal development of Labuan to be put into a regional perspective.

3.1 PROCESSING OF THE IMAGE

The data were processed to give a regional overview. In local areas the enhancement was not optimal and could be improved by targeted processing. The basic process was that of contrast enhancement which distributes the recorded values across the full display range of the computer monitor; the main effect being to increase the separation between different spectral responses. On the land area a filtering operation was used to make the image appear sharper. Final image was formed by combining information from the visible part of the spectrum in the offshore areas and infra-red information onshore. In describing colour compositing of different bands the convention used here is that the bands are assigned in order to the red, green and blue display colours.

To achieve this combined image, a mask was made using one of the infra-red bands to separate the land and water; the water areas appearing black on the infra-red scene. Some narrow rivers may have not been fully included as water on this mask so they appear to be

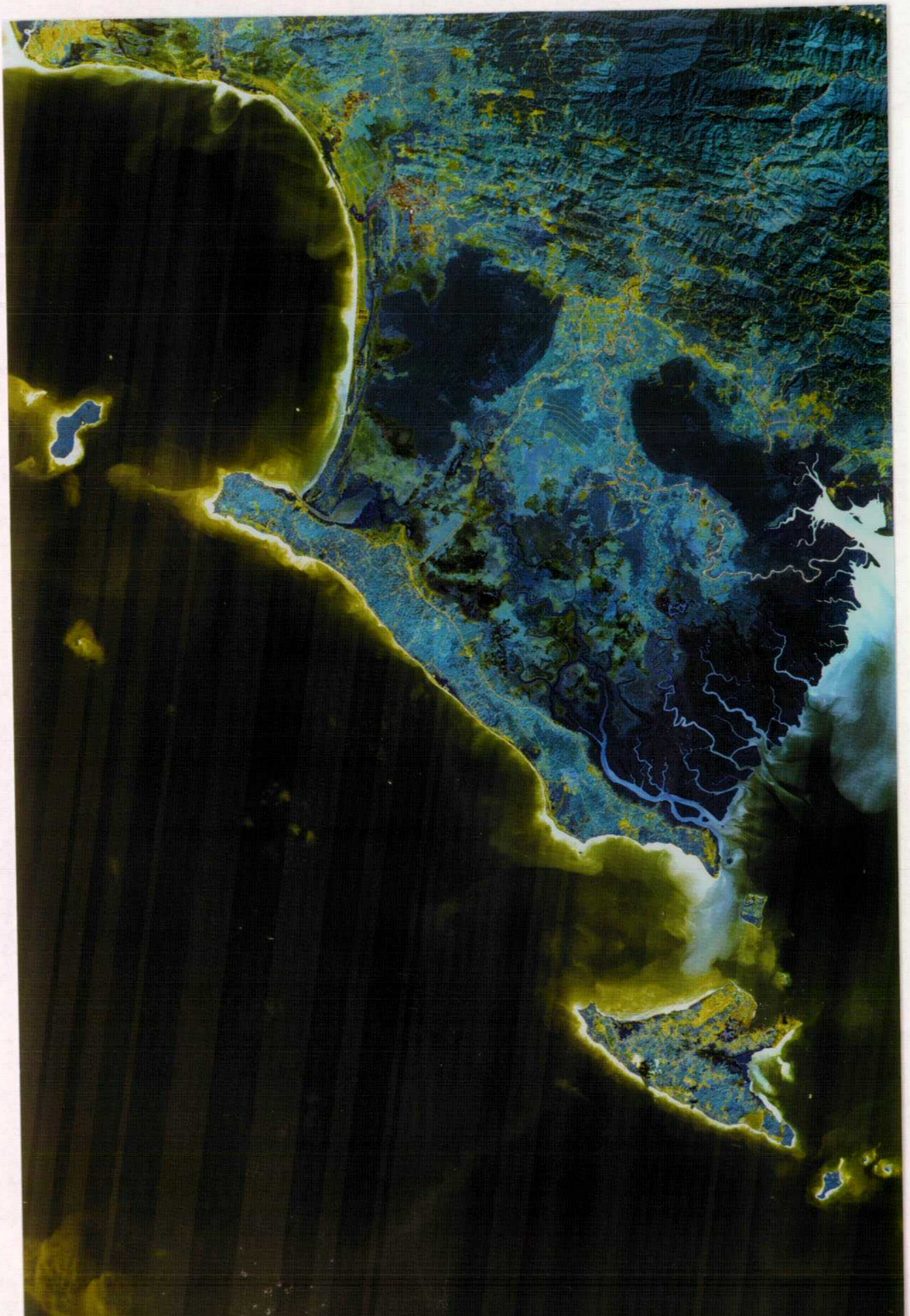


Figure 21a Landsat scene 118/96, 14 June 1991 of Labuan and western Sabah

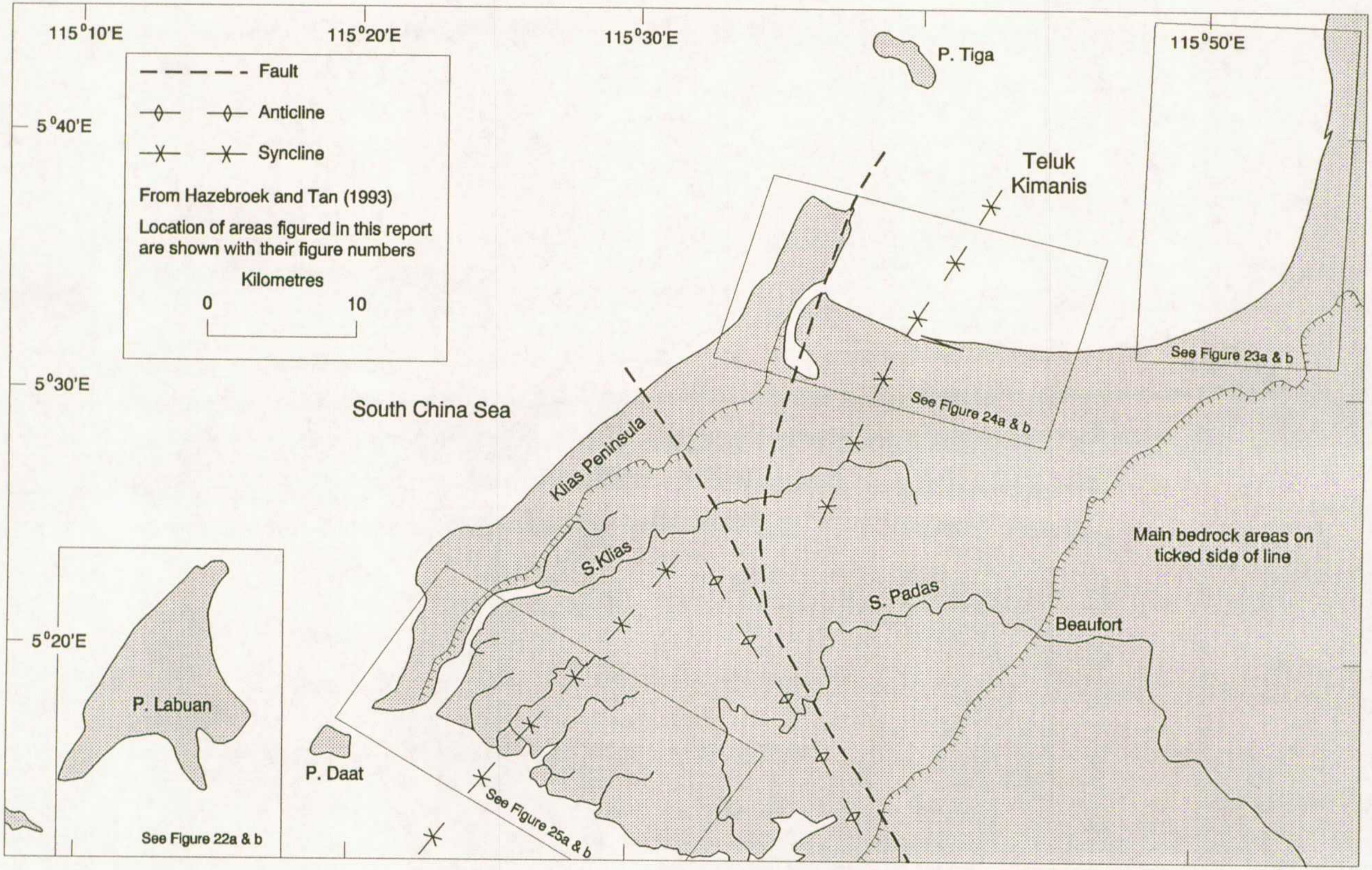


Figure 21b Interpretation of the major morphogenic features of the Landsat scene covering Labuan and western Sabah

made up locally of cubes of alternating colour, this is an artefact. Some narrow rivers have reflectance in the infra-red band due to their suspended sediment content and appear dark blue on the image. In addition the production of the mask led to edge effects producing locally a thin indigo line along the coast. Having created the mask the onshore and offshore parts of the scene were processed separately using different Landsat bands.

TM Bands 3, 2, and 1 (Red, Green and Blue wavelengths), within the visible part of the spectrum, were used for the offshore region since water does not reflect the infra-red energy and thus appears black on an image. The offshore part of the scene, therefore, appears close to its natural colour. The shortest wavelength band (TM Band 1) penetrates water the most as shown by the range of blue colours on the scene.

Two factors, the bathymetry and the suspended sediment load, control the colour of the water, and the two can generally be differentiated on colour, with the suspended sediment plumes displaying a slight buff tint, and the bathymetry variations within the blue colour range. Near the coast high reflectance from the suspended sediment and sea bed saturates the zone which on this scene is commonly a narrow white strip. Additional information could have been obtained from this zone but at the expense of degrading the scene from deeper water.

TM Bands 4 (Near infra-red), 5 (Shortwave infra-red) and 3 (Red) were used to produce the onshore part of the image. TM Band 3 responds to the red chlorophyll absorption band of healthy green plants and is important for discriminating different types of vegetation. TM Band 4 is useful for determining biomass content and crop identification. TM Band 5 shows maximum reflectance off bare rock and is also sensitive to soil moisture contents. The blue/green coloured areas on the image represent bare soil and are most noticeable in the discrete areas where the forest cover has been cut down or roads, or paths cut through the vegetation. The extent of vegetation removed from Labuan compared to mainland Sabah is particularly noticeable. Built up areas also display a blue colour but with a characteristic a rectilinear pattern. Areas of bedrock are easily differentiated from the lowland areas by their texture, uniformity and type of vegetation.

No attempt has been made in this report to interpret the bedrock areas for the focus is on the lowland, coastal and offshore part of the scene.

3.2 REGIONAL GEOLOGICAL SETTING

The island of Labuan lies off the western end of the Klias peninsula and north of Brunei Bay (Figure 21b). The northwestern limit of the peninsula is a linear ridge formed of Tertiary clastic sediments of Oligocene to Miocene age, similar to those forming Labuan. Between the ridge and the upland part of the Sabah mainland to the southeast, is the lowlying area formed of sediments deposited by the Ss. Klias and Padas. The region forms part of the "Inboard Belt" of the Sabah continental margin and the tectonic setting shown in Figure 21b is taken from Hazebroek and Tan (1993). The points to note are the synclinal structure trending NNE-SSW from Teluk Kimanis in the north through the low lying deltaic area to Brunei Bay; the oblique anticlinal structure crossing the deltaic area; and the series of strike-slip faults crossing the area. Uplift and erosion due to transpression following large scale strike-slip movement of the Inboard Belt occurred in late Miocene to Holocene times leading to the feeding of new depocentres to the west (Baram Delta) and northwest (the Outboard Belt). The NW Sabah margin is presently tectonically relatively quiet though an earthquake measuring 5.0 on the Richter scale occurred in May 1991, some 75 km off NW Sabah (Hazebroek and Tan, 1993).

The degree of tectonic control on Quaternary, and specifically Holocene sedimentation in the area is uncertain. The modern lowlands are probably of Holocene age though the delta was probably a major feature through the Pleistocene. The offshore seismic profiles run by GSM around Labuan show at least two Quaternary units preserved in East Channel, and both are cut by an infilled channel with a base at about 120 m below sea level. No information is known on Quaternary sediments beneath the modern Klias/Padas delta, but it is presumed that during the late Quaternary sea level lowstand the river flowed seawards in an incised channel from Beaufort, where the S. Padas reaches the coastal lowlands. The location of the modern drainage divide in the northern part of the lowlands (Figure 21b) may suggest local tilting, but the divide lies about 15 km northeast of the structural anticline feature shown by Hazebroek and Tan (1993).

The gross form of the lowlands forming the Klias peninsula (Figure 21b) consists of the delta of the river S. Padas discharging from the highlands at Beaufort and forming a widening arc which meets the bedrock ridge forming the northwestern coast of the peninsula. Before the delta extended to the ridge the river flowed both north and south into Teluk Kimanis and Brunei Bay. Once the river reached the ridge it flowed to the south cutting off sediment supply to the northern coast of the peninsula which became modified by longshore drift and wave action as described in 3.2.2

The different delta-front morphologies found on the northeastern and southwestern shores of the Klias peninsula are a function of the balance between river, tide and wave forces. The peninsula coast facing Teluk Kimanis is wave dominated with limited river and tidal importance. Along the southwestern shore of the peninsula, facing Brunei Bay, wave energy is less important and river input greater than along the north coast, though tidal effects are essentially the same along both coasts (see also James, 1984).

3.2.1. The Landsat image of Labuan and its adjacent waters

This example from the scene provides an indication of the use of the Landsat image in determining bathymetry, mapping the nearshore zone, and discriminating vegetation types.

3.2.1.1 Bathymetry

Figure 22a shows part of the scene covering Labuan, and Figure 22b is an interpretation of the scene. The bathymetric contours used to compile Figure 22b have been taken from a number of Hydrographic Office Charts. The scene was processed to achieve as much information as possible from across the whole offshore area, and not to achieve maximum discrimination within the nearshore zone. There is a correlation between the white, saturated areas on the scene (Figure 22a) and the limit to the intertidal areas as marked by the 0 m contour (equivalent to the lowest tide level). When the scene was taken tidal levels were high and the 0 m isobath was covered by about 2 m of water (Figure 22b). This correlation is best developed on the western and southern coasts of the island. The boundary to the white saturated zone is commonly gradational over about 100 m and may lie slightly inside or slightly outside the 0 m bathymetric contour. Along the east and south coast there are extensive areas with a blue colour within the 0 m contour. The correlation between colour of the zone and water depth is a complex function of both suspended sediment levels and reflectance from the sea bed. (See Photo 35). The colour in the zone is more blue, and the waters more transparent, where the suspended sediment concentration is less. The better underwater definition on the shallow (<2 m) western parts of the Menumbok Banks (Figures 25a and b) may be due to very low suspended sediment concentrations in this area of limited wave activity.

On the west coast of the island, seaward of the white-saturated, coastal zone, the slightly deeper water has a lighter blue colour which becomes darker with depth, and achieves an uniform saturation at a depth of less than 5 m. Isolated lighter blue patches offshore represent coral reefs with crests less than 5 m below the surface.

The correlation of the blue colour with water depth becomes more complex off the eastern coast of the island. The complicating factor being the interplay between the input of suspended sediment plume from the S. Klias to the east, and the influx of clear oceanic water entering the East Channel from the south. The location of this plume moves with the tidal stream and its size is determined by the river output. The westward and northward sweep of the plume implies the tide, at the time the scene was collected, sweeping northeastwards through East Channel. Thus Victoria Harbour and the coast off Tg. Taras are swept by clean water which has a dark blue tone on the scene even though the water is relatively shallow. In contrast the waters off the east coast of the island are generally lighter in tone even in deeper water, and parts of the deep channel west of P. Daat over 20 m deep have a light blue tone. The distinctive light orange plume out of S. Klias represents the plume prior to significant mixing, the variable areas of lighter blue tone off the east coast of Labuan represent significantly mixed and diluted plumes from the same source.

The waters in the inner part of Victoria Harbour (Photo 47) display a distinctive pale pink/brown colour similar to the lagoon on Figure 24a. This appears to be a different tone from the suspended sediments discharging from the major rivers (Figure 25a) and this colour appears typical of brackish water. James (1984, p.17) notes that a feature of the rivers in Brunei is a distinct brown colouration due to tannins derived from adjacent peat swamps, and this plume of coloured water may extend into the sea where it is sometimes mistaken for hydrocarbon pollution. This feature should be recognizable on the Landsat image and the brownish colour of the brackish water may be due to this effect.

Ibrahim and Cracknell (1990) investigated the bathymetry around Penang Island, Malaysia, producing a Landsat-3 density sliced image of Multispectral Scanning System (MSS) Band 4. The intensity of pixels of the MSS Band 4 image displayed an exponential correlation with water depth which could be used to a depth of about 37 m. Mapping and bathymetry of a shallow coral lagoon on the Cook Islands has been described by Loubersac (1989) using the three SPOT channels and by Khan, Fadlallah and Al-Hinai (1992) in using Landsat TM Bands 1 and 2 for mapping of subtidal coastal habitats of carbonate sediments in the Gulf Coast of Saudi Arabia. In all three cases ground verification assisted the interpretation which in the case of the bathymetric mapping was especially prone to error due to variation in the reflectance of the various substrates. These studies show that the images are best used to map

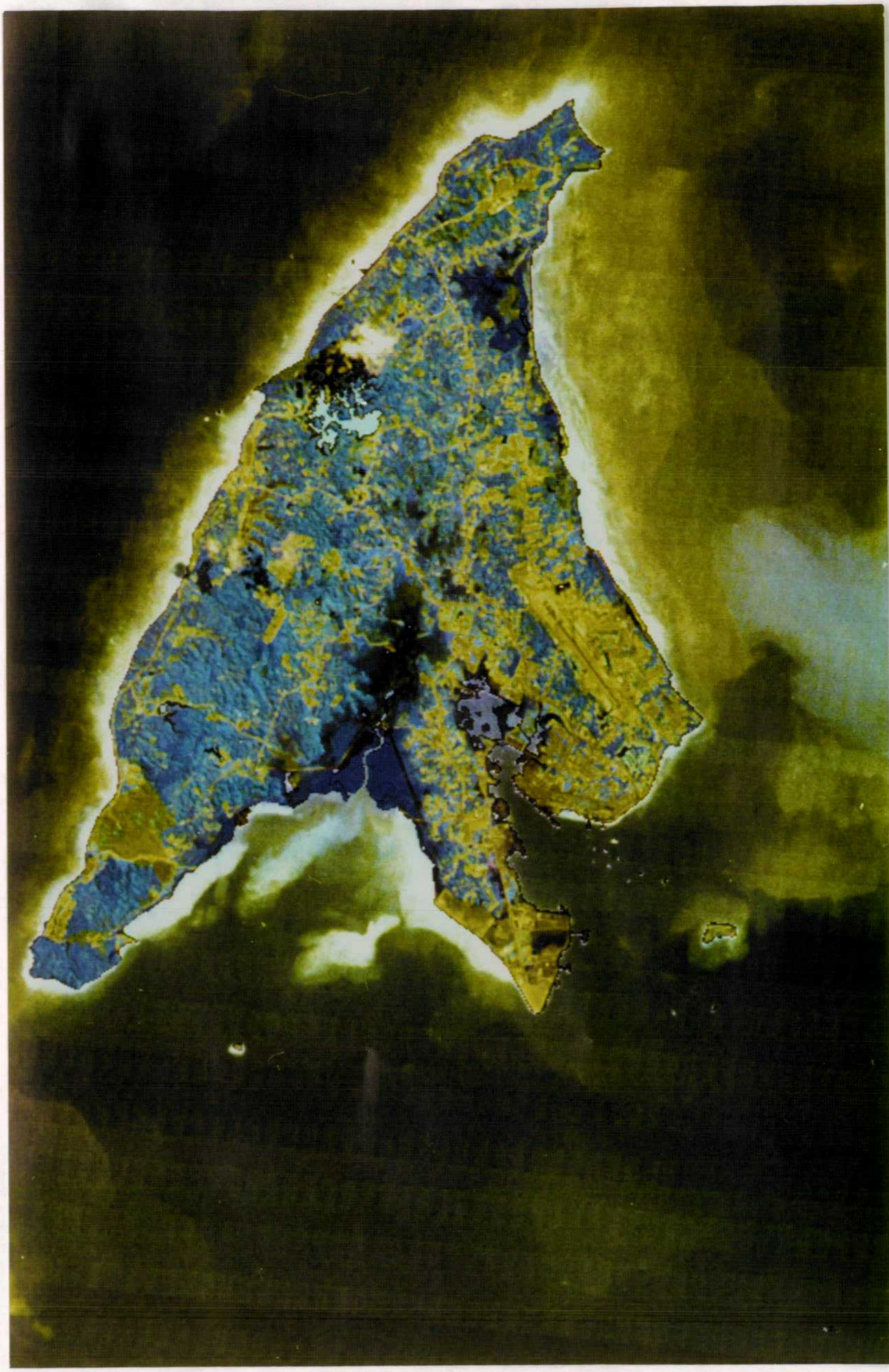


Figure 22a Landsat scene covering Labuan and surrounding waters

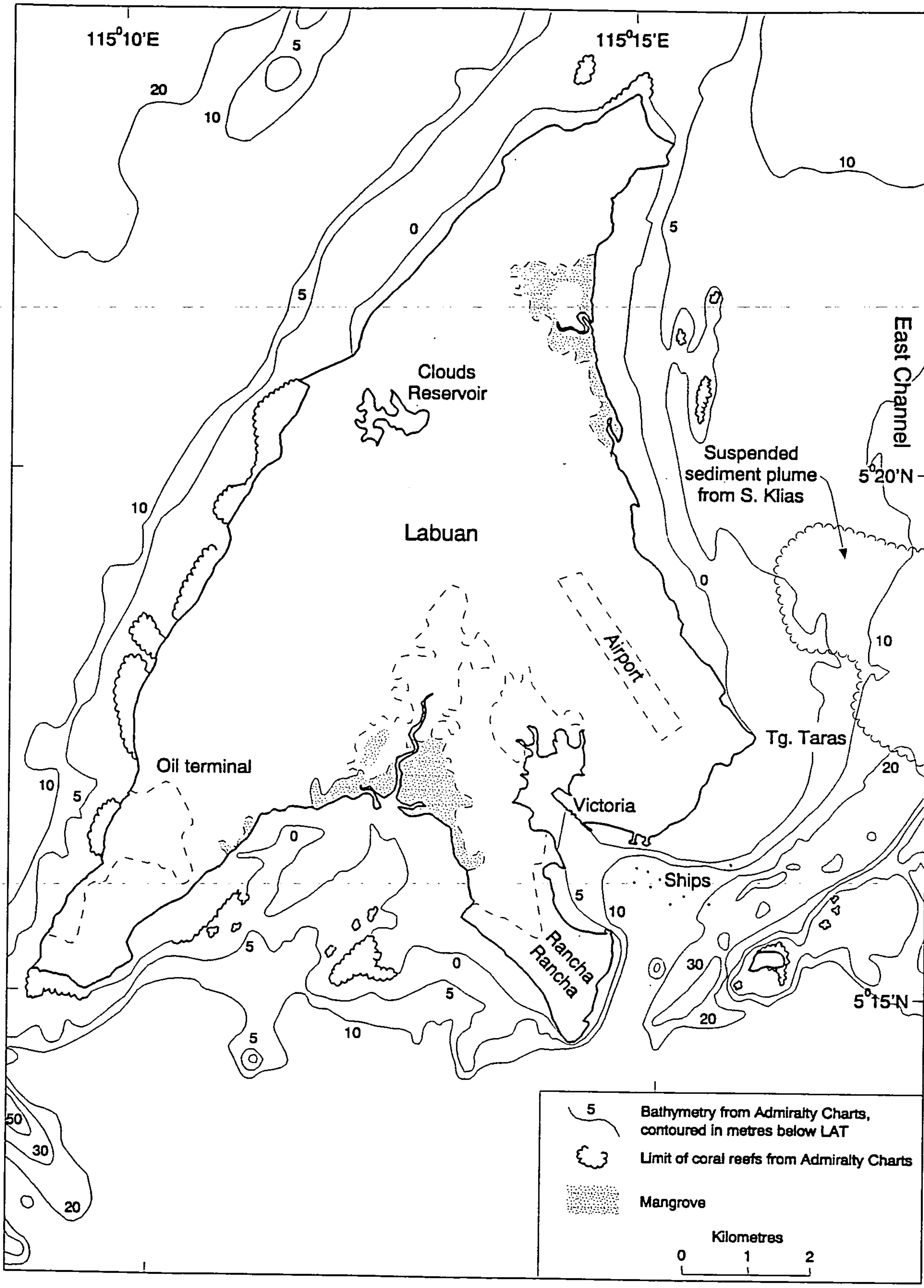


Figure 22b Interpretation of the Landsat scene covering Labuan and surrounding waters

habitats in clear shallow marine water after ground truthing, and the reliability of bathymetric data from the images is highly dependant on water quality.

The conclusion here is that the form of processing employed for this scene, and the conditions of the sea water do not permit an adequate interpretation of the bathymetry and morphology of extensive parts of the nearshore waters. Processing aimed specifically at determining the bathymetry of the nearshore zone would have been successful along parts of the coast. Other workers have attempted to investigate these specific problems with better results, but these are usually in areas of low suspended sediment concentrations.

3.2.1.2 Landuse

The onshore part of Figure 21a was processed using Landsat TM Bands 4 (Near infra-red), 5 (Shortwave infra-red) and 3 (Red).

On Figure 22a Labuan is divisible into four main colour tones.

1. The blue areas represent areas of limited vegetation cover. Vegetation is largely absent from the Rancha Rancha reclamation, the airport, the urban area of Victoria, and substantial part of the vegetation has been removed from the oil terminal site. The patchwork of blue across the island identifies areas cleared for cultivation or building.

2. The pale orange-brown areas represent the normal vegetation on the island. The tone and texture of these areas are generally uniform unlike on the bedrock ridge on the Klias peninsula where at least two distinct sub-types are identifiable within this general tone. A similar variation is seen on the Sabah upland covering the easternmost part of the scene (Figure 21a): the sub-type absent from Labuan may represent tropical hardwood forest.

3. The uniform brown-red colour at the mouth of S. Kina Benuwa, along S. Ganggarak, around the shores of inner Victoria Harbour, and a small area behind Tg. Aru, represents mangrove forest (see Photos 43, 46 and 48). Note the dark blue line across the mangrove in the southern bay, representing dead vegetation resulting from laying of an oil pipeline across the lowlying area. Note the village of Kg. Berbulah on the western shores of Kina Benuwa Bay.

The darker indigo-blue colour forming an landward extension to the mangrove forest is a swamp, probably fresh water, with a vegetation signature distinctive from that of the saline-influenced mangrove. More extensive areas of such swamps are also common landward of the mangrove in the lower reaches of the S. Klias.

Figure 13 is interpretation of the geomorphological features of island produced by GSM from air photographs. Comparison of Figure 21a with this figure shows that the remote sensing image accurately identifies the mangrove but the alluvial flats and raised beach on the western coast were not identified from the processing used to produce this image.

3.2.2 The beach ridges of Teluk Kimanis

The Landsat TM image shows the southern and eastern coast of Teluk Kimanis made up of coast parallel beach ridges, the largest of which are about 100 to 200 m across and up to 8 km long (Figures 23a and b; 24a and b). The "packets" of ridges are most complex on the eastern coast of the bay and the younger ridges are better resolved on the image than the older ridges; possibly because of degradation of the older ridges by agriculture. In the northeastern part of the bay the ridges form parts of a southward extending active spit system, and the linearity of the moribund ridges in the southern part of the bay suggests a similar origin. The ridges are visible on the scene due to vegetation differences between their drier crests and wetter intervening lows. The ridges are formed by wave action moving sediment along and onshore. The packets of ridges form indicate subtle changes in wind direction and sediment supply into the nearshore zone.

No major rivers enter the bay and at the coast, the mouths of all the small rivers are diverted to the west by longshore drift. On the southern coast the exit of the S. Binsulak is diverted 12 km westward by the ridges. The littoral drift produces accumulation of sediment in the western part of the bay and the cut off a lagoon measuring 4 km by 1.5 km at Kuala Penyu. The southwestern part of Teluk Kimanis, off Kuala Penyu, is therefore shallower than the east coast due to a build up of sediment in this part of the bay (Figure 24a and b).

The variations in the suspended sediment and bathymetry of the nearshore waters of the bay highlight on the Landsat scene a bathymetric channel some 150 m wide and 1500 m long extending seawards from the lagoon behind Kuala Penyu with a hint of a small ebb delta at its seaward end. A very much smaller channel, similarly formed by a tidal jet, extends seaward from the mouth of the S. Binsulak.

The shallowest part of the bay shows as white on the scene with a range of lighter blue, rounded diffuse areas extending out into deeper parts. The Admiralty Chart shows that the intertidal zone is generally less than 200 m wide on the eastern side of the bay, widening to about a kilometre in the southwest corner. A hint of this submerged wide intertidal flat is visible on the scene as shown in Figures 24a and 24b. The whiter areas extending about 1.5 km into the bay are plumes of suspended sediments, they do not relate to outflows from specific rivers, and may be the result of local nearshore rip currents. Less well defined plumes of suspended sediment are visible up to 8 km out into the bay. Better defined suspended sediment eddies occur off the northeastern part of the Klias peninsula and around P. Tiga.

3.2.3 The Sungai Klias delta

Figure 25a shows the Sungai Klias delta in the northern part of Brunei Bay, and Figure 25b is an interpretation of the image. Two rivers, S. Klias and S. Padas enter the northern part of the bay and their deltas coalesce. The course of the former is about 40 km long and the latter is over 160 km long. The drainage basin of the latter is lowlying, and its sediment load consequently low; but the drainage basin of the latter includes the western Sabah uplands and carries a larger sediment load. The difference in load is very clear on Figure 21a, with the extensive offshore plume occupying Teluk Padas at the mouth of the S. Padas, and the smaller more discrete plume discharging west of the mouth of S.Klias.

The distribution of infilled meander belts within the lowlands suggest that the main channel of S.Padas, has in the past, followed a different course from the present one. Previously the main channel flowed to the west and southwest crossing the lowland between the modern courses of the main rivers. James (1984) described the river regimes in Brunei as "flashy" showing frequent and rapid rises and falls in response to rainfall in the hills on the catchment. This irregularity produces flooding on the lowlying alluvial plains which probably also occurs in the lowlands fed by the S. Padas.

S. Klias is the main river entering in the northwestern part of Brunei Bay but a number of other intricate meandering channels, forming an interconnecting distributary network, practically unconnected to the river system, and with lengths of up to 15 km, feed into the bay between the mouths of the Klias and Padas. This channelled area constitutes the lower delta.

The gross form of the delta front, forming the northern coast of Brunei Bay, is straight, and faces southwestwards into Brunei Bay. Generally this form of delta front reflects wave dominance, but the wave energy in the bay is low, being protected from the dominant NE monsoon winds and open to the SW monsoon only across a fetch of about 40 km. The shape of the delta front taken from the highwater line on the Landsat image collected in 1991 compared with that taken off the 1960s topographic maps of the same area shows no change in the location of the channels; erosion measuring between 100 to 200 m has occurred along a limited length of the western coast, and the only substantial accretion has occurred on the two small islands at the mouth of, and about a kilometre southwest of the mouth of S. Padas.

The subaqueous delta plain (the inter- and sub-tidal part of the delta lying seaward of the lower delta) is very shallow with an inter-tidal zone (above Chart Datum which is approximately the level of Lowest Astronomical Tide) between 2 to 4 km wide. The sub-tidal part of the prodelta is about a kilometre wide, and its seaward limit is marked by an abrupt increase in water depth from about 5 to 20 m. Most of the centre of Brunei Bay is flat with a depth slightly greater than 30 m. This prodelta steep margin surrounds much of the southeastern and northeastern margins of the bay suggesting that fluvial sediments discharged into this part of the bay are limited in volume and are retained on the prodelta. In contrast the extensive Sunda Bank in the southwestern corner of the bay is a more extensive prodelta built out from sediment deposited by a number of rivers (Figure 10).

Subtidal channels are seen on the Landsat image east of the mouth of the S. Klias. The linear to slightly curved channels are up to 3 km long, between 200 m to 900 m across, and widen to seaward. Water depths in the channels are rarely more than a metre at low water and the Mean Tidal range is this part of the bay does not exceed 1.5 m (Admiralty Chart 1844). These channels are formed by the jet of tidal and fresh water discharging from the rivers into the bay. A low bar occurs at the mouth of the largest of the channels but its amplitude is probably less about a metre. A similar but larger and longer, linear channel discharges from S. Limbang in the southwestern corner of Brunei Bay (James, 1984).

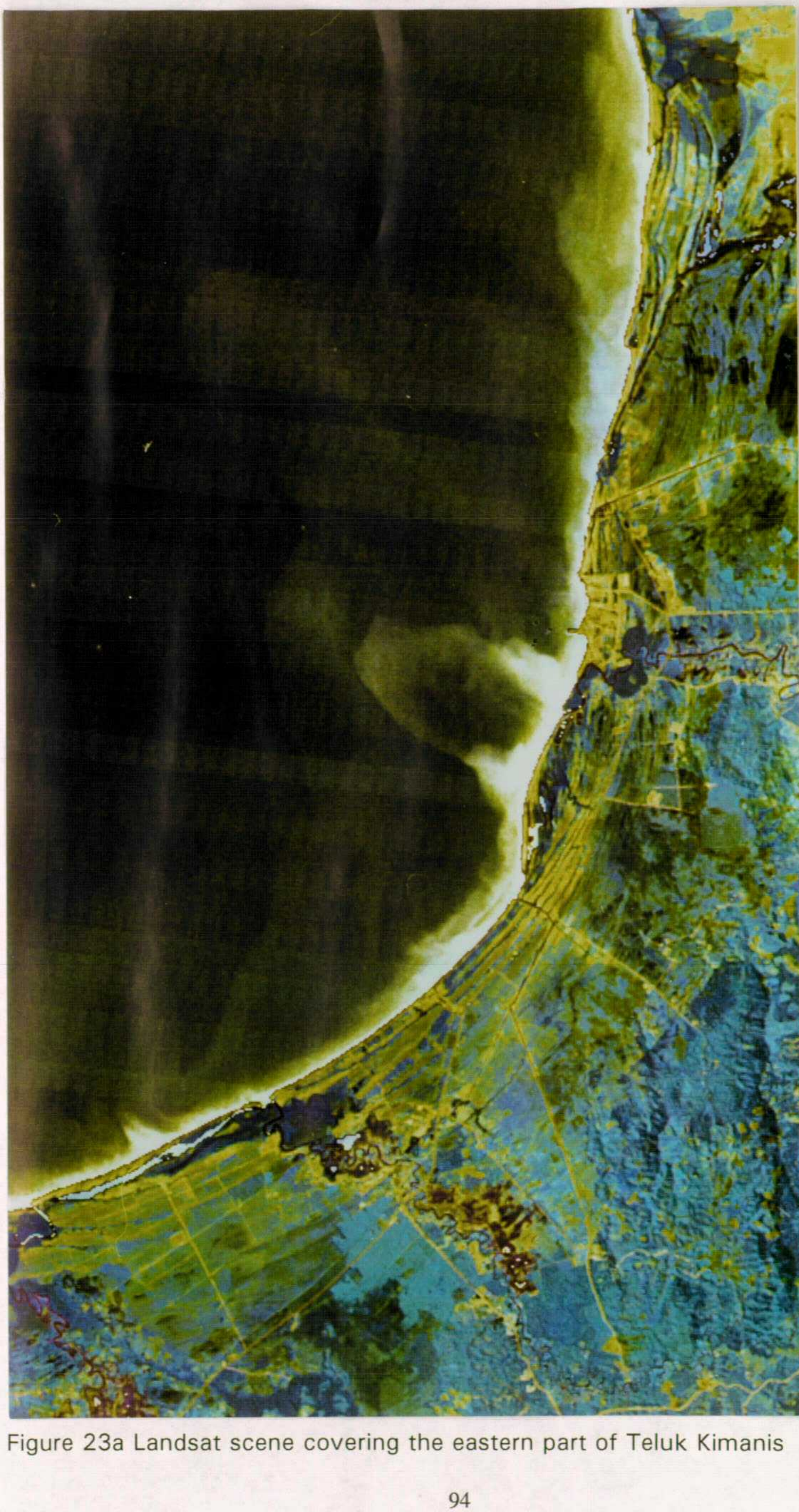


Figure 23a Landsat scene covering the eastern part of Teluk Kimanis

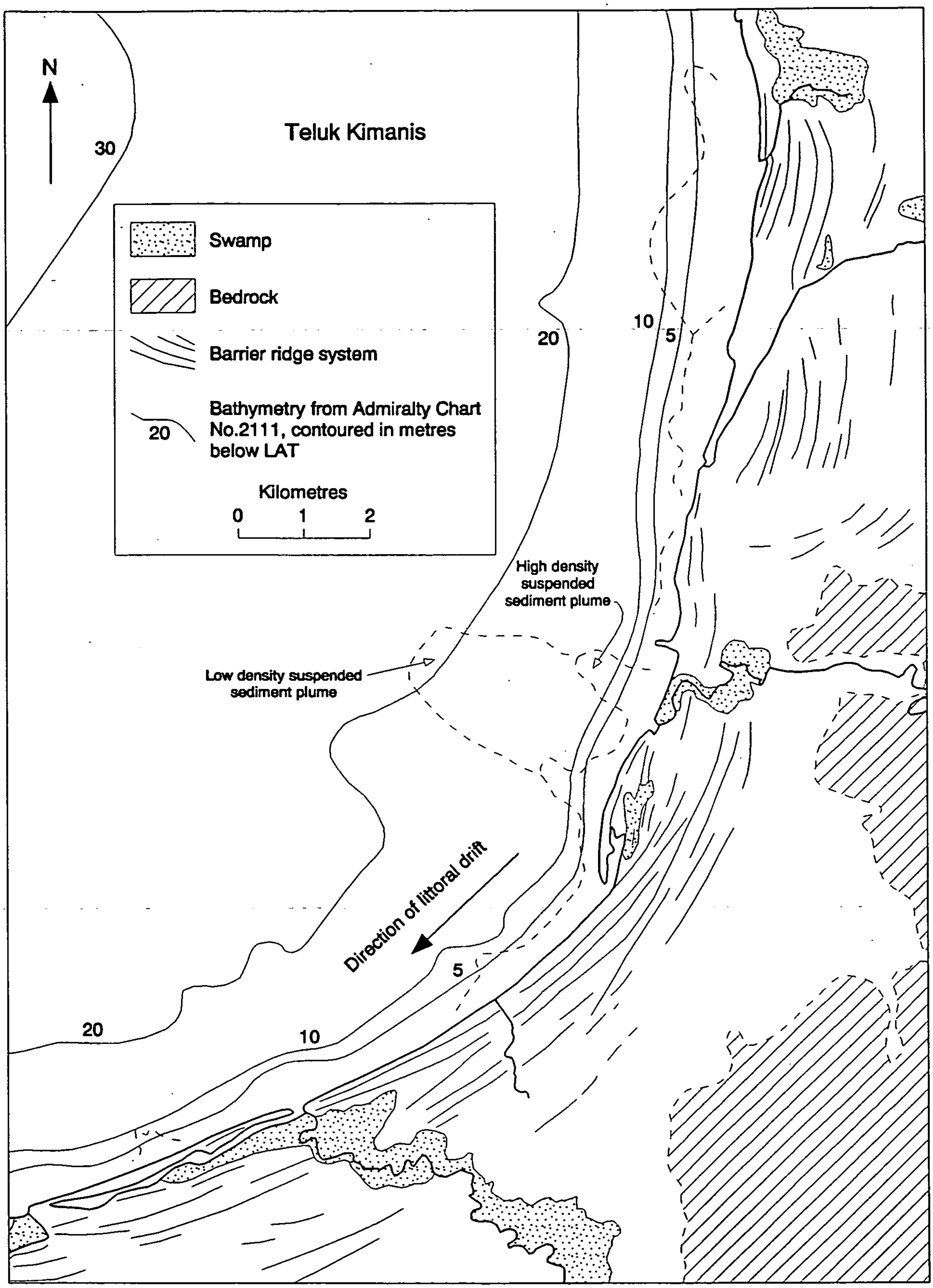


Figure 23b Interpretation of the Landsat scene covering the eastern part of Teluk Kimanis

Mainland Sabah was not visited during the project and further interpretation of the S.Klias and Padas deltas is based on a comparison between the Landsat scene and the descriptions of the Mahakam delta from eastern Kalimantan (Carbonel and Moyes, 1987, and Gastaldo, Allen and Hue, 1993), the Baram delta, Brunei, (Caline and Huong 1992), and the Klang Langat deltas Western Malaysia (Coleman and others 1970).

The Mahakam delta has been the subject of detailed investigation over the past 20 years led by French workers (see Allen and others, 1979), and much of the published work is centred on the sedimentology and ecology of the delta. The delta has a classic birds foot form and covers some 5000 km^2. The delta has two active distributary systems separating an intervening interdistributary area in which there are a series of tidal channels practically unconnected to the fluvial regime. The average depth of the channels is between 7 to 10 m which is considerably deeper than the Klias and Padas deltas. The upper delta is covered by a hardwood tropical forest, and the lower delta is forested by Nipa (also called *Nypa*) palm swamps. Coastal mangroves colonise newly formed tidal flats and aggregational headlands. Mangrove also colonise channels in the lower delta where salinity gradients are generated by tides. Gastaldo and others (1993, Figure 2) shows the distribution of major vegetation types within the delta. The delta front fringing the delta plain is an intertidal to subtidal platform 8 to 10 km wide with an abrupt edge at a depth of about 5 to 10 m where the water deepens to about 35 m over a distance of a kilometre.

Examination of Figure 22a using the above information as a guide suggests that the Klias and Padas deltas have a three-fold vegetation/morphological subdivision. The lighter brown circular area representing the older, and upper delta northwest of Beaufort; the mixed, and complex indigo and dark brown coloured area to the north west of this zone representing low swamp trapped in the zone between the two coasts; and the predominantly dark reddish brown areas representing the lower delta and covered by Nipa palm and mangrove. The uniform dark red brown areas forming part of the latter sub-type may represent mature peat as described from the Baram delta.

The Baram-Belait delta on the coast of Brunei (James, 1984; Caline and Huong, 1992) is a Holocene feature formed of clays, sands, gravels and peats, reaching nearly 60 m thick near the river mouth, which has been growing seaward by 10 m/year over the past 4 500 years. The form of the delta is largely a function of waves rather than tidal or fluvial processes. The near balance which exists between the longshore drift induced by the NE and SW Monsoons results in a symmetrical shape of the delta about its main distributary (Caline and Huong, 1992, Figure 5). The rapid growth of the Baram-Belait delta may have been equalled by the Klias-Padas delta except that the latter has been constrained between the Klias peninsula and the mainland and does not form so prominent a morphological feature.

Caline and Huong (1992, Figure 3) used Landsat imagery to divide the delta into a number of environments; onshore the delta was divided into an upper delta plain covered with freshwater peat swamps and a lower delta plain with mangrove swamps. Active and abandoned fluvial systems traversed the whole delta plain. The freshwater swamp was further divided (their Figure 4) into a supermature peat, mature peat developed along abandoned river bed and crevasse splays, mature peats developed in inter-river bed areas, inactive peats developed along the river bed and mixed peat fine-grained sediments. These five types of swamp were correlated with the plant communities described by Anderson (1964). Mangrove

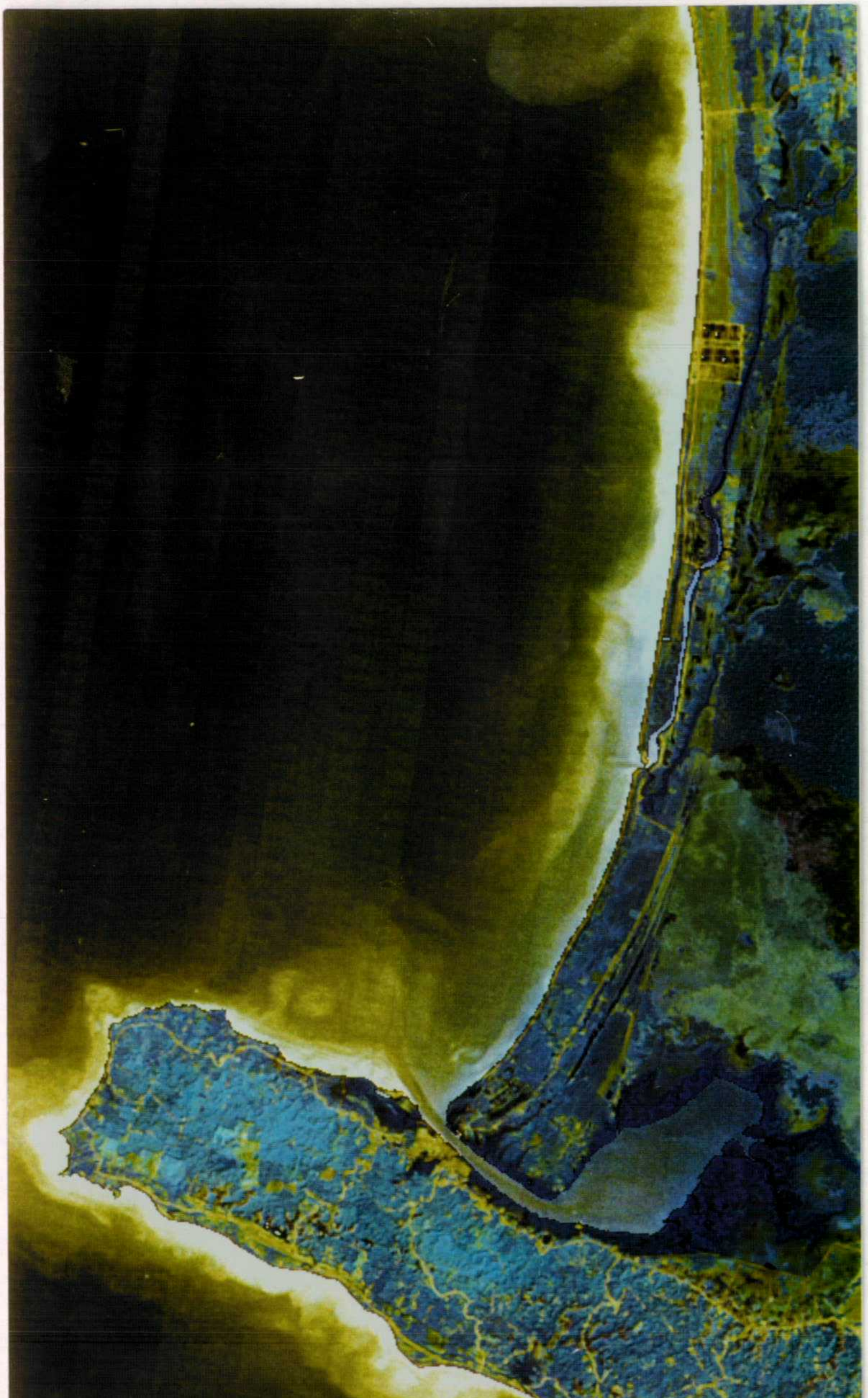


Figure 24a Landsat scene covering the southwestern shores of Teluk Kimanis

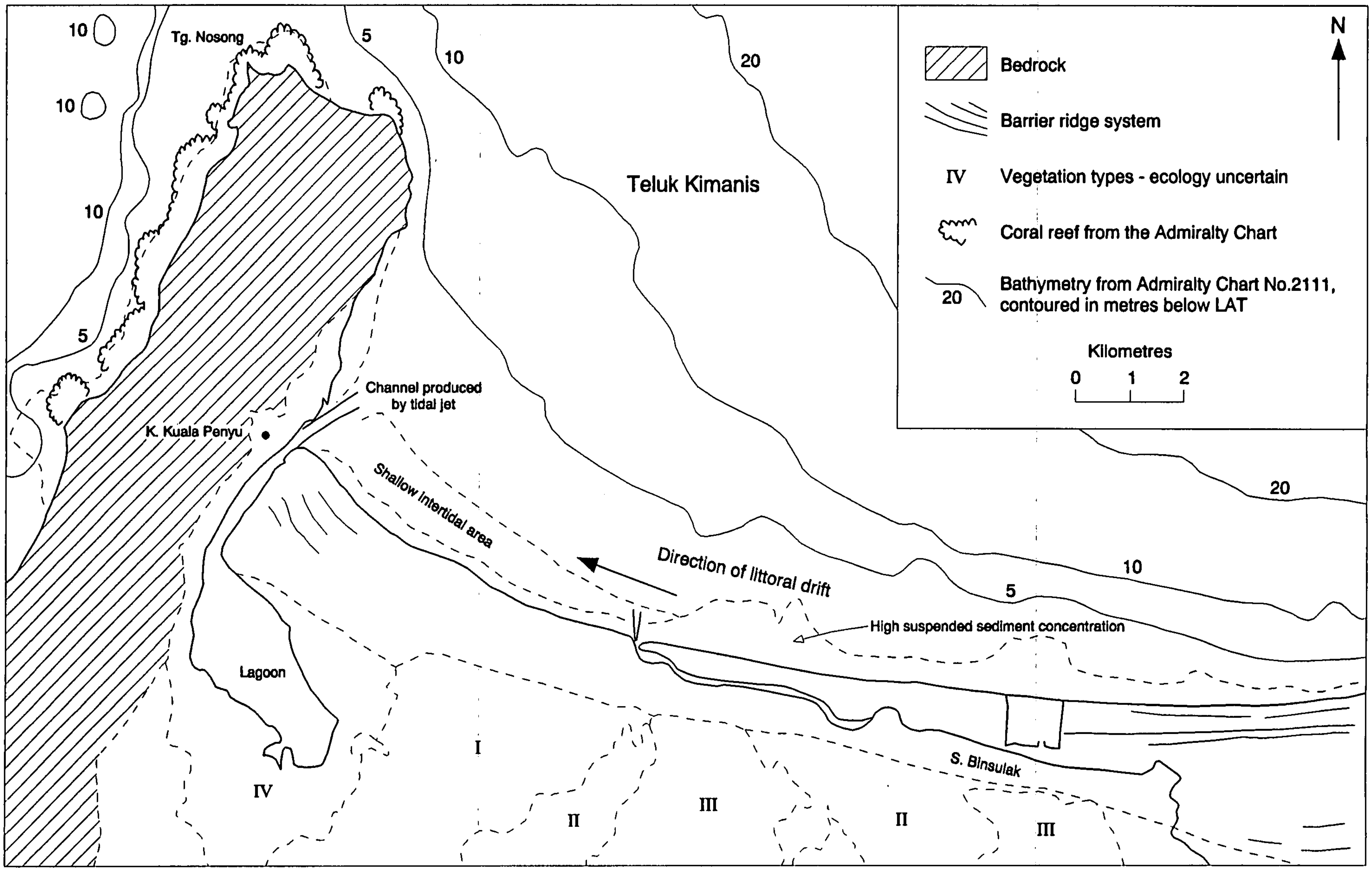


Figure 24bInterpretation of the Landsat scene covering the southwestern shores of Teluk Kimanis (also termed the "Nipah Belt") was identified along the lower reaches of the Rivers Baram and Belait.

Direct comparison of the above distribution of environments with that on the S.Klias delta is problematic for although the Landsat image shown in Caline and Huong (1992) is the product of Bands 3, 4 and 5 (as is Figure 21a), they give no indication of the display colours assigned to each band. Thus, each environment shows a different colour from Figure 22a. If Caline and Huong (1992) have followed the red, green, blue display convention then it is questionable whether TM Band 5 has been used since there is clearly a signal reflected from the water column which would not normally be the case with infra-red data. Consequently, either the red, green, blue display convention has not been used or a different band combination is shown; in either case a comparison between the colours of the images is not possible.

The study of the Klang and Langat deltas of western Malaysia described by Coleman and others (1970) was based on field investigation and air photographs. The deltas differ from the Klias and Padas deltas in being formed in areas of high tidal range (4.1 m) and strong currents. These factors have produced a different morphology to the deltas but the vegetation zonation and processes controlling sedimentation remain similar. The paper discusses the sedimentological aspects of Watson (1928) who described a range of mangrove forest types from the area, and related them to five classes on the basis of height and frequency of tidal inundation. This study highlights the complexity of vegetation types and the care needed before using remote sensing to distinguish between them. Coleman and others (1970, Figure 10) showed a diagrammatic cross section of the active delta which is represents a suitable analogy for the Klias and Padas deltas, except that the substrate is likely to be muddier in the Sabah deltas than those facing the Malacca Straits.

The isopach map of peat distribution of the Tg. Karang (Coleman and others, 1970, Figure 15) shows peat deposits (up to 6 m thick) building up higher than the elevations attained by the natural levees of the adjacent rivers.The basal peat was dated at 4540 years BP and is underlain by grey clay with roots and burrows. In the Klias peninsula the areas interpreted as mature peat (Figure 21b) are located on either side of the S. Padas as it emerges northwestward onto the lowlands at Beaufort. The arc of agricultural land forming the upper delta in Figure 21a and 21b may therefore be topographically slightly lower than peats on either side.

3.2.4 Vegetation classification

Discrimination of the Landsat scene into specific vegetation types may be achieved by classification according to defined reflectance and biomass parameters. Previous mapping (see the 1:50 000 topographic maps of the area) divided the lowland zones of this region into mangrove, Nipa palm, swamp, peat, tropical hardwood. It was not the remit of the project to carry out a vegetation classification of the scene, but an example of this approach, as applied to mangrove is discussed below.

Moreau and Vercesi (1989) and Bertrand (1989) described the use of SPOT data for mapping mangrove in Guinea, and Populus and Herz (1985) described a similar project using Landsat

Figure 25a Landsat scene covering the delta at the mouth of the S.Klias

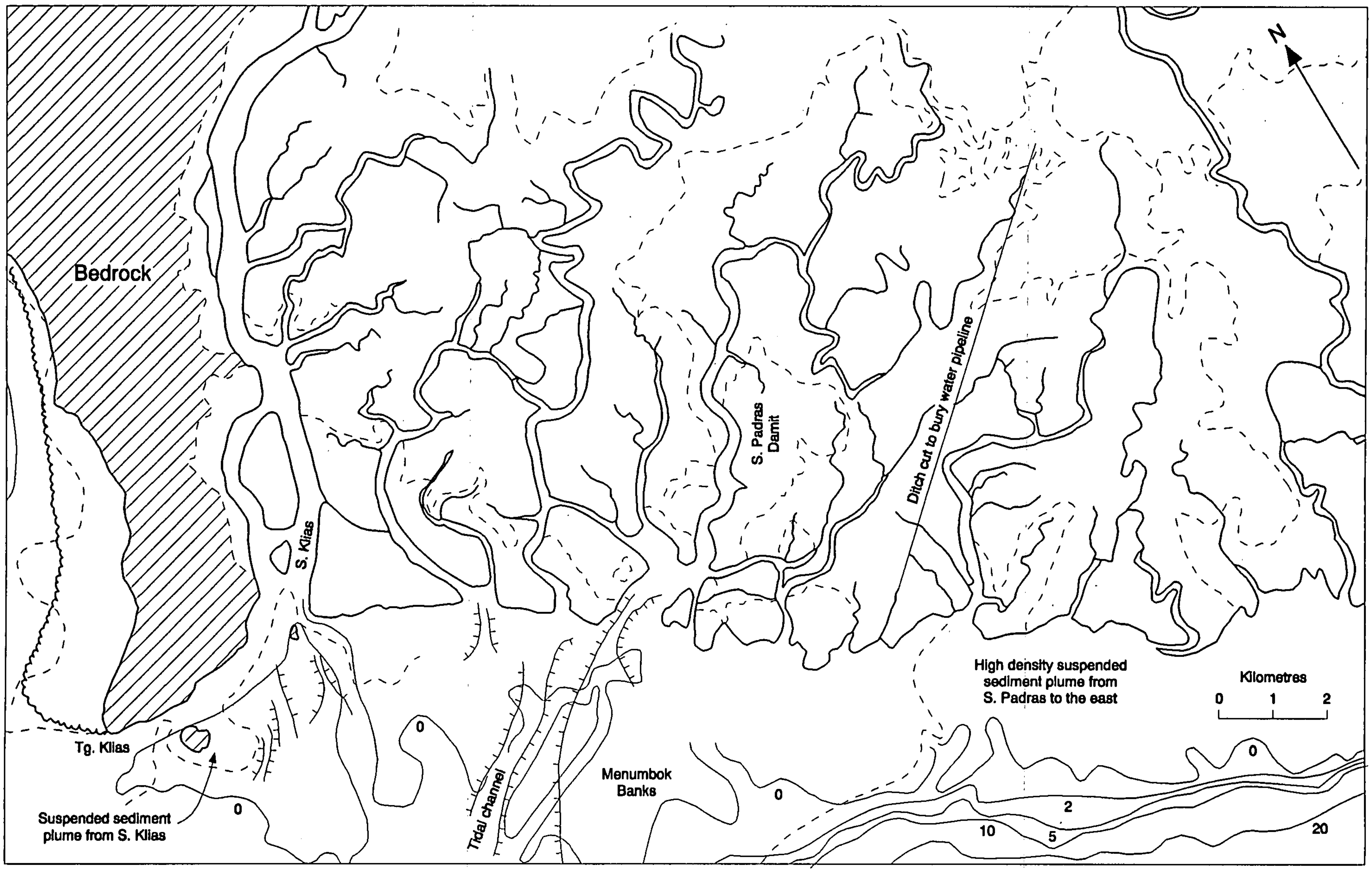


Figure 25b Interpretation of the Landsat scene covering the delta at the mouth of the S. Klias. Bathymetric contour in metres below Lowest Astronomical Tide

on the southeast coast of Brazil.

In Brazil, panchromatic and oblique coloured photographs were collected from a height of 150 m to determine the major physical and biological features of the mangrove. The Landsat scene was collected during low tide and a colour composite made up of TM Bands 2, 3, and 4. The internal structures of the mangrove revealed by the image were confirmed by photo-interpretation and field data. The intertidal zone shows as two major units, purplish red vegetation representing mangrove, and lighter coloured bare ground, either wet and covered by high organic content, or dry and covered by grassy vegetation.

The biomass-index (the ratio of TM Bands 4/3), which is proportional to the vegetation density, was used to classify the scene. The scene was then divided, based on threshold values, into wet sand, bare sand, low and scattered mangrove swamps, and two types of high and dense mangrove. The results met the 1:50 000 scale mapping objective and the best results were considered to be likely from data collected during the wet season.

In Guinea infrared photographs were considered to be the most reliable means of discriminating various taxons within the mangrove. The SPOT data were too coarse to yield similar data on the mangrove but classification is possible into nine zones, largely using the biomass-cover density.

In both countries ground checking and aerial photography was used to verify the remote sensing imagery. Projects in the nearshore zone are unlikely to be able to afford verification programmes for all the aspects of interest (bathymetry, suspended sediment loads, mangrove mapping etc.) and full use should be made of existing data from the region.

3.3 Usefulness of remote sensing for coastal zone mapping

Landsat imagery provides an excellent, cost effective means of carrying out an initial geoscientific interpretation of an extensive (measuring tens of kilometres) coastal zone. The approach is especially suited for remote areas with difficult access. For smaller sections of coast, especially where access is simple aerial photography and field checking provides more focused result. UNESCO (1986) dealt with the use remote sensing in the coastal and oceanographic field.

The limitations mentioned above are valid if the Landsat image is being used only to produce a single scene to replace or improve on existing maps. However, significantly more information can be obtained from the Landsat data with processing and classification focused on specific parameters.

The Landsat data comes into its own when processed to address a specific problem. Bathymetry of the coastal zone from Landsat data is always likely to be of limited usefulness in all but the clearest waters, and along tropical lowland coasts its value for this use is generally limited. Where the waters are clear then submarine features (tidal jet channels and banks, and coral reefs) are well displayed but may be better resolved on a suite of specially collected air photographs.

The Overseas Development Administration has recently funded a project to assess the cost-effectiveness of remote sensing techniques for application to tropical coastal zone management. This project is being carried out in the Caribbean and will include a comparison of a range of remote sensing imagery.

A number of examples have been brought to the authors attention of unpublished, more detailed analysis of remotely sensed data from the coastal zone in Malaysia carried out by the School of Applied Physics at the University of Dundee. M.Sc. theses completed in October 1995 include:

- coral reef mapping for Western Malaysia - G. Schwamborn
- identification of sediment plumes in the mouth of the River Klang -Richard Hall
- remote sensing of Malaysia's sea grass - Jason Probert
- marine and terrestrial resource mapping of Palau Tiga - John Apling

These studies focused on specific problems and utilised the full potential of remote sensing to the issues. Additional local studies have been carried out in Malaysia some of which were published in the 10th Asian conference on Remote Sensing held in Kuala Lumpur, Malaysia in 1989.

The project by John Apling on P.Tiga set out map the island and nearshore habitats of the island which is situated north of the Klias peninsula (Figures 21a and b). The island, which measures about 5 km by 1.5 km has been designated a Marine Park and identification of the present habitats provides a reference against which to measure future change.

The image was processed in the usual way with geometric and atmospheric corrections followed trimming to a subset covering the study area. The land and water parts of the image were then identified and processed separately. Contrast enhancement followed by multispectral band and principal components analysis allowed classification of the image. This was translated into a land and shallow marine resource classification after groundtruthing the classified areas.

The results were encapsulated into three topics. The bathymetry of the study area was deduced using the MicroBRIAN system which possesses an automated function to calculate zones of varying water depth based on the ability of Landsat TM Bands 1-4 to penetrate the water columns to varying degrees. TM Band 1 penetrates to 25 m, Band 2 to 15 m Band 3 to 5 m and Band 4 to 0.5 m. Bands 5, 6 and 7 do not penetrate the water column. From these results Aplin (1995) produced a map showing four depths zones plus the zone with depths >25 m. Suspended sediments in the water column and differing sea bed substrates distorted the results which were not plotted in the thesis against the known bathymetry.

The shallow water area was classified into shallow sand/mud, rock, mixed sand/sargassum/mud, algae/dead and live coral, sargassam/coral, sand and sargassam in depths 5 to >8 m, sand 3 to >10 m, deepwater (>25 m) and sediment plumes. Again suspended sediment plumes confused the classification. The plumes were easily identified in the deeper water but less easy to infer in shallow water.

Onshore the land was divided into three vegetation classes, mangrove, cleared areas of sand and trees and sand. The vegetation in the classes were checked and groundtruthed during the field visit.

This project provides an example of the detail obtainable from remotely sensed data when a small specific area or problem is examined. The technique is extremely powerful for mapping habitats within the coastal zone but needs considerable groundtruthing for the classifications to be reliable.

4.CONCLUSIONS

The need for a database embracing a range of geoscientific data from the coastal and offshore zone was identified by a number of geological organisations from southeast Asia. These organisations were collecting substantial quantities of data, but it was not being systematically entered onto a database, and they would therefore have difficulty incorporating it into any GIS system in the future.

The database established in this project forms the basis for a nation-wide system which could operate for many years. The database accepts a number of datasets common to the nearshore and offshore environments, and can also be adapted for a wider range of geoscientific data. The Geological Survey of Malaysia recognised the long-term value of such a system and the Marine Geology Group has set up successfully a digital database, as outlined in Part 1 of this report.

The database was set up on PCORACLE but could also run using a number of similar software packages, and most organisations in the region have suitable software. What perhaps is more important is the recognition by these organisations of the discipline and uniformity of collection and labelling necessary to enable the data to be put into the database. Without such discipline at the data collection stage the chances are slim of setting up a large nation-wide geoscientific database.

Maps may be generated from the database and examples are given in the report, but this necessitates additional software and procedures which are not covered fully by the project. As with the GIS, map making can only be carried out from a clean, validated database. It should be noted that the GSM are now using the database to generate maps and report diagrams.

The case study on Labuan, Eastern Malaysia demonstrated the wide range of geoscientific data related to coastal zone management. Some of the information, sample sites, particle size analysis, seismic profiles and geophysical measurements could be put directly into the database tables set up for the project. Other data sets such as tidal current information and stratigraphic results would need new forms to be prepared.

Once a database and map making facility are available for the coastal data then a move is possible into digital cartography. The bathymetric maps and diagrams for this project were produced and manipulated using the Intergraph Microstation system. The remote sensing results represent yet another set of data that can be integrated with the database results.

Within many geoscientific disciplines the world is moving towards geographic information systems, digital cartography and remote sensing, but the first two of these are underpinned by a well founded relational database. This project has demonstrated a database based on and approach used successfully by the British Geological Survey in coastal environments. It is now up to groups within the national geological surveys to establish and maintain a database along these lines if they are to move further into using the new technologies mentioned above.

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PHOTOGRAPHS
Locations shown on Figure 16

26. Wide, gently shelving beach on the west coast of Labuan. (Film 3.7)

27. Wide, rocky foreshore within bay enclosed by Tg. Layang Layangan. (Film 3.25)

28. Logs accumulating at high water line, west coast of Labuan. (Film 1.27)

29. Surface of beach on the west coast of Labuan consisting of quartz sand rich in poorly sorted coral debris. (Film 3.11)

30. View looking landward of the raised beach on the west coast of Labuan. (Film 3.32)

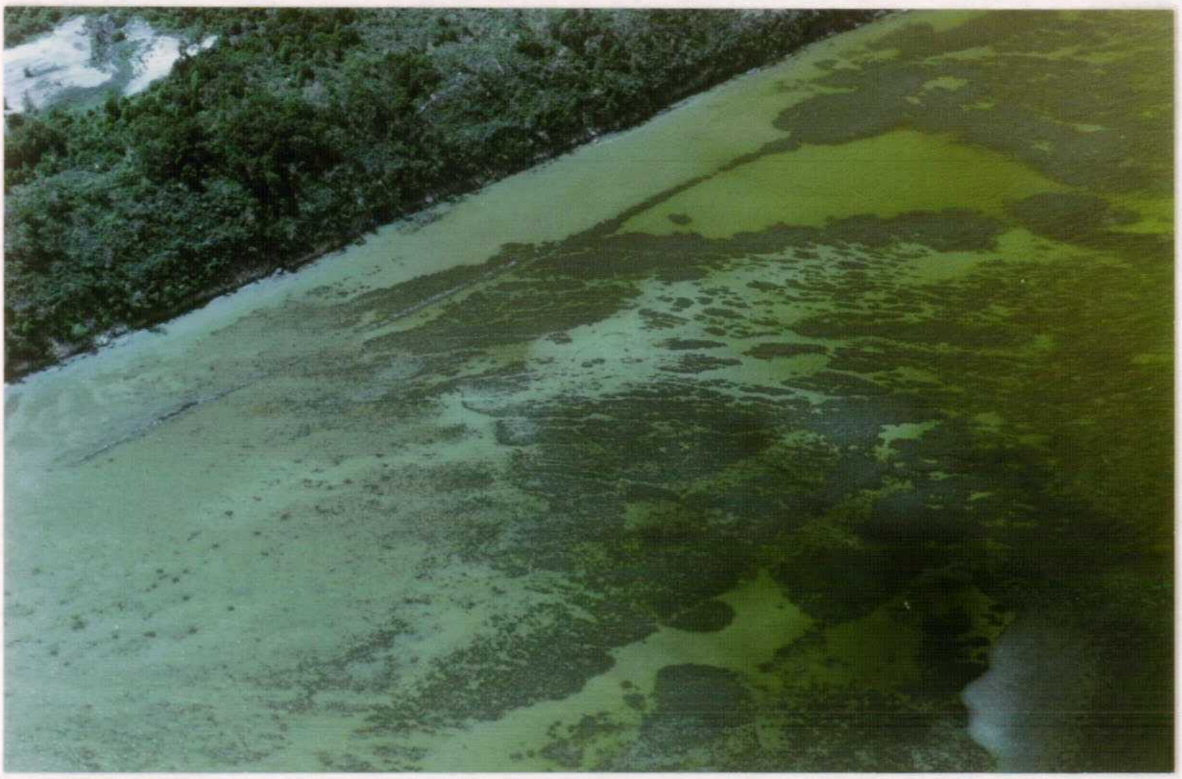
31. Toppling trees western Labuan, indicating an eroding coast. (Film 3.10)

32. Nipa palm stranded on an eroding beach, west coast of Labuan. (Film 3.31)

33. Low wirebasket (or gabbion) wall protecting a road, west coast of Labuan. (Film 3.9)

34. Wide, rocky foreshore northern coast of Labuan. (Film 1.21)

35. Oblique air photograph of coral reefs off Tg. Layang Layangan. (Film 1.8)



36. Beachrock on the eastern coast of Labuan. (Film 1.31)

37. Upper/lower beach morphology, eastern coast of Labuan. (Film 2.3)

38. Fallen coconut palms in an area of rapid erosion, eastern coast of Labuan. (Film 2.10)

39. Eroding mangrove, eastern coast of Labuan. (Film 2.6)

40. Wirebasket (or gabbion) wall protecting an electricity sub- station near S. Ganggarak.(Film 1.29)

41. Newly constructed house with protective sea wall, eastern coast of Labuan. (Film 2.5)

42. Beachrock on the lower beach, next to a damaged jetty built in 1981, eastern coast, Labuan. (Film 2.13)

43. Southern end of Tg. Aru spit, eastern coast of Labuan. (Film 2.14)

44. Mangrove development on accreting lower beach in front of the Tg. Aru spit, eastern coast of Labuan. (Film 2.15)

45. Beach at Jalan Membedi, eastern coast of Labuan. (Film 2.25)

46. Cliff erosion in Tg. Taras cemetery, southeastern tip of Labuan (Film 2.29).

47. Mangrove development inner part of Victoria Harbour. (Film 1.15)

48. Two-fold beach profile, southern coast of Labuan. (Film 3.1)

49. Accreting mangrove, southern coast of Labuan. (Film 3.5)