APPLICATION OF REMOTE SENSING TECHNIQUES IN GEOLOGICAL MAPPING OF THE NAIROBI-KAJIADO-MACHAKOS AREA

By

ONYWERE, SIMON MANG'ERERE

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science (Geology) in the University of Nairobi.

Department of Geology
University of Nairobi
P.O. Box 30197
NAIROBI
KENYA.

1990

This thesis is my original work and has not been presented in any other university.

....

ONYWERE, SIMON MANG'ERERE

This thesis has been submitted for examination with our knowledge as University Supervisors

....

DR. STEVE J. GACIRI

SUPERVISOR AND CHAIRMAN, DEPARTMENT OF GEOLOGY.

....

MR. BENSON G.O. MBOYA

SUPERVISOR

ABSTRACT

APPLICATION OF REMOTE SENSING TECHNIQUES IN GEOLOGICAL MAPPING OF THE NAIROBI-KAJIADO-MACHAKOS AREA

By

SIMON MANG'ERERE ONYWERE

The study deals with the application of space images in geological mapping of the Nairobi-Kajiado-Machakos area. A visual interpretation is made. The spectral analysis is made using standard photographic false colour composites (FCC) and black and white satellite imageries.

In the visual image analysis, linear features that were observed both in small scale (1:500,000) and large scale (1:125,000) are described. A discrimination of the geology on the basis of the radiometric or tonal signatures is also made. The linear features to the west of the area are a result of tectonic activities in the East African Rift System that lead to faulting of the rocks. These linears correspond to faults. The linear features to the east are associated with the striations on the Precambrian metamorphic gneisses of the Mozambique Belt. They represent a relic of the original sedimentary structures.

Using the standard false colour composite (FCC) the area was broadly divided into two on the basis of spectral reflectance characteristics and textural patterns. The

Precambrian metamorphic rocks to the south and east are mainly in the yellow/brown colour hues and the volcanics to the west are in the blue/green colour hues. A detailed analysis of five selected areas in these broad divisions is made basing the interpretation on a number of measurable and recognizable features on the images including geometric shapes or forms and patterns. The information from the image is field checked and together with collateral data is compiled into a refined map, a synthesized geological map of the Nairobi-Kajiado-Machakos area.

ACKNOWLEDGEMENTS

I should like to express my sincere appreciation to Dr. S.J. Gaciri of the Department of Geology, University of Nairobi for not only serving as my advisor and supervisor, but also for initiating my attachment to the Regional Centre for Services in Surveying Mapping and Remote Sensing (RCSSMRS), and kindly helping me with the field data collection strategy. His guidance, comments and criticism greatly helped me in structuring this research effort. I am also thankful to Mr. B.G.O. Mboya also of the Geology Department for kindly serving as my supervisor on my thesis committee and offering me very constructive criticism.

Many sources and other individuals have contributed to this work. The Centre (RCSSMRS) provided all the pertinent equipment which I used to make my interpretation, prepare the maps, produce images for illustrations and type this report. To the Centre I am most grateful. I register my appreciation to the Centre staff who, either directly or indirectly helped me during my stay at RCSSMRS. In particular I would like to thank Mr. L. Isavwa for arranging my field trips and allowing me to use the Photo-Laboratory facilities to prepare the image illustrations. I also thank Dr. A. Falconer and Mr. J. Baraza for consultations, Mr. G. Adika for consultation on cartography of the maps and Mrs. L. Okara and Mrs. C. Ogada for typing this work.

I am thankful to the West German Academic Exchange Services (DAAD) for sponsoring me during my second part of my M.Sc. course and generously providing funds to complete my field trips. I owe my gratitude to the Department of Geology of the University of Nairobi for making this arrangement possible.

My gratitude also go to the Office of the President (Government of Kenya) and administrations of the four districts, Nairobi, Kiambu, Kajiado and Machakos, for granting me permission to use the topographic maps of the area. They also afforded me an opportunity to visit the entire mapping area. To the Ministries of Planning and National Development (Department of Resources Surveys and Remote Sensing (DRSRS); Water Development; Environment and Natural Resources I also thank you for consultations.

I also wish to thank my wife Margaret, for her moral support and encouragement.

TABLE OF CONTENTS

Page

List of Figures

Page

List of Tables

List of Plates

List of Abbreviations Used in the Thesis

ASAL	Arid and Semi Arid Land
CAV	Colour Additive Viewer
CCT	Computer Compatible Tape
DAAD	Deutscher Akademischer Austauschdienst d'Echanges (West German Academic Exchange Services)
DN	Digital Number
DRSRS	Department of Resources Surveys and Remote Sensing
EM	Electromagnetic
ERTS	Earth Resources Technology Satellite
FCC	False Colour Composite
Landsat	Land Satellite
MOMS	Modular Optical Multispectral Scanner
MSS	Multispectral Scanner
RBV	Return Beam Vidicon
RCSSMRS	Regional Centre for Services in Surveying Mapping and Remote Sensing
TM	Thematic Mapper

CHAPTER ONE

1. INTRODUCTION

1.1 Aims and Scope of Study

The study aims to achieve the following objectives:-

(1) To examine the effectiveness and assess the suitability and capacity of satellite data - Landsat's Thematic Mapper (TM) and Multispectral Scanner (MSS) and Space Shuttle Mission's Modular Multispectral Scanner (MOMS) photographic imagery - in detecting and mapping geological features in the Nairobi-Kajiado-Machakos area.

(2) To prepare a synthetic geological map of the Nairobi-Kajiado-Machakos area and indicate the potential of satellite imagery of the earth for geological research in inadequately mapped parts of Kenya.

(3) To evaluate the land resources of the area, such as vegetation resources, hydrogeology, settlement pattern and demographic pressure, and indicate their influence on geological interpretation of the area.

1.2 The Study Area

1.2.1 Location

The study area is situated just to the east of the central portion of the East Africa Rift Valley in Kenya and to the south of Mount Kenya (figure 1). It lies between latitudes $1^{o}10$'s and $2^{o}00$'s and longitudes $36^{o}40$'E and $37^{o}30$'E (plate 1). It covers an area of approximately 110km x 110km. The main working image in this study was Landsat-5 TM frame number 168-061 (Kenya).

1.2.2 Infrastructure

The area is served by tarmac roads that link the major towns - Nairobi (capital city), Athi River, Kajiado, Machakos, Tala, Masii, Ruiru and Kiambu. Smaller towns especially those located to the north west of the area are also linked by tarmac roads. Loose surface roads and other smaller roads that are passable only during the dry weather, link market centres in the whole area. A railway line passes centrally from south east to north west through the area. Nairobi is the main railway station. A branch of the railway line run from Konza through Kajiado to the Kenya Marble Quarry in the south west.

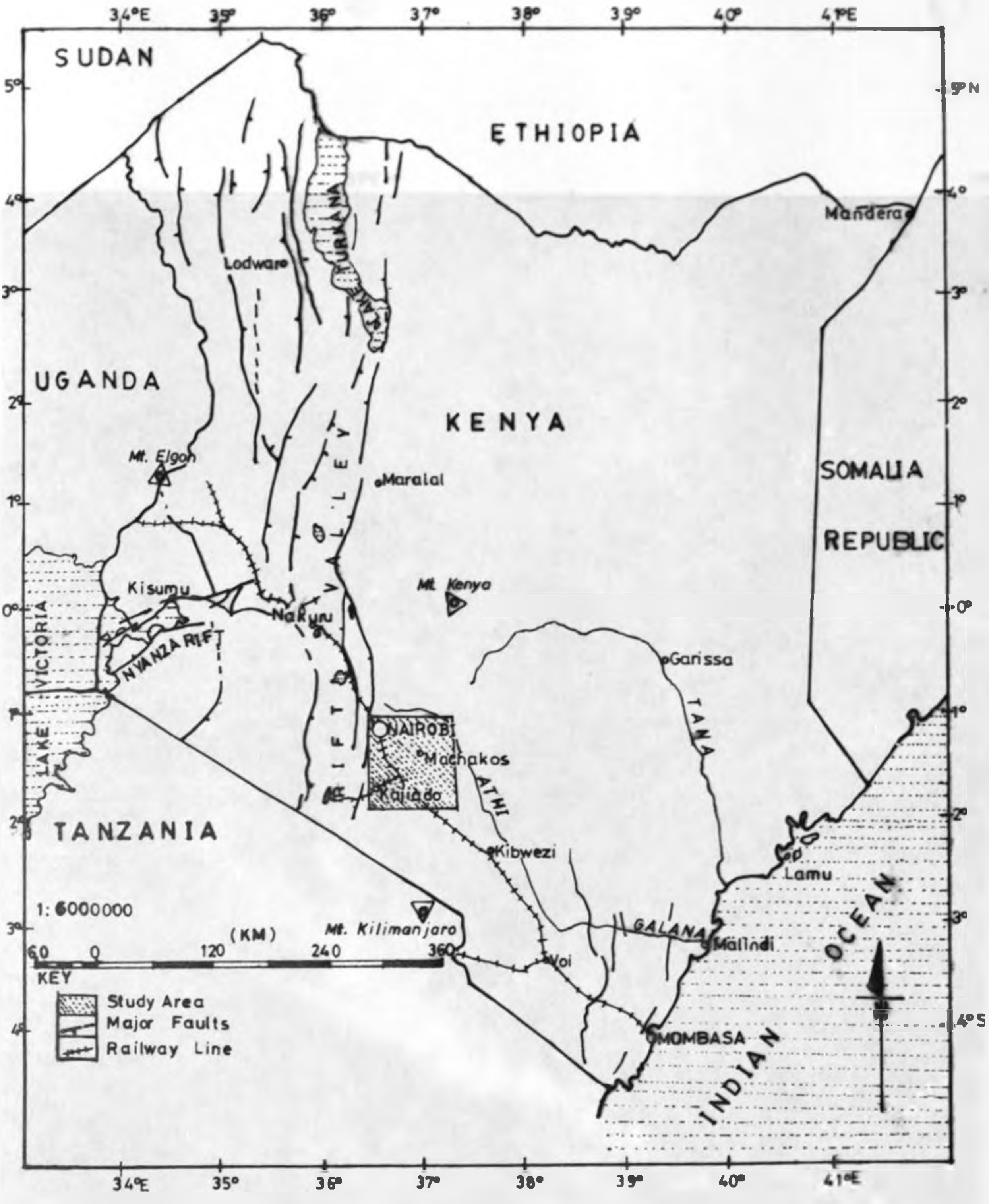


Figure 1- Map of Kenya showing the location of the study area.

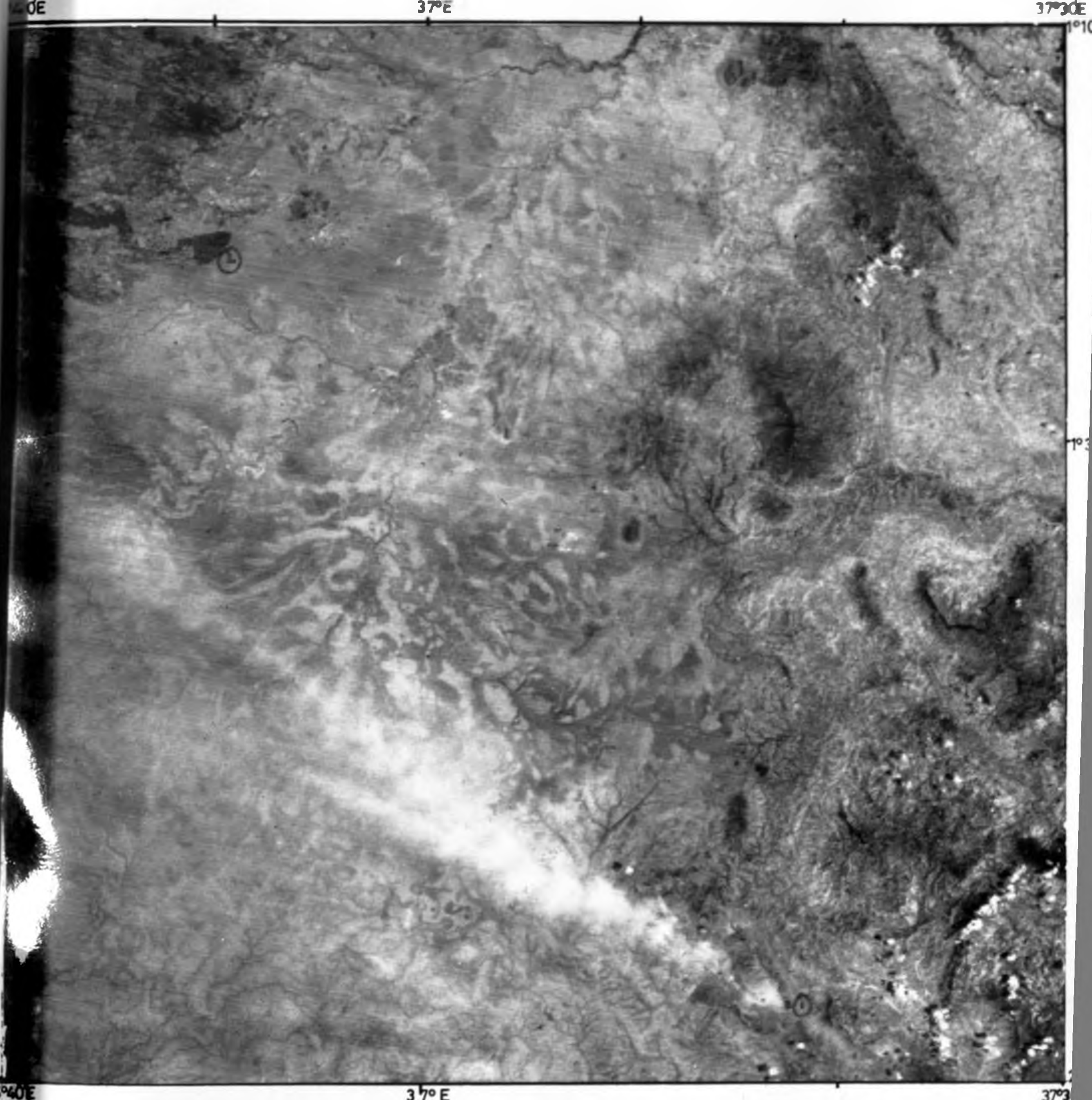


Plate 1. A black and white landsat-3 MSS image acquired on 11 Feb. 1976 at a scale of 1:500,000 showing the full extent of the study area. Note the conspicuous Precambrian metamorphics and their strike in the east, the lava plains in the west and the cultivated ground in the north-west.

1.2.3 Climate

Data of meteorological observations are available for the various towns in the area. Annual rainfall varies from about 2065 mm in the north west of the area around Kiambu to 1700 mm in the plains east of Nairobi, to 1200 mm on the foothills in the eastern parts. The rainfall rises to about 2125 mm on the hill tops of the highest hills in the Machakos area. These figures are quoted (Ministry of Water Development) for the spell of the long rain season from March to May. For the short rain season, November to December, the rainfall varies from 1125 mm in the Kiambu area to 825 mm in the plains east of Nairobi and 500 mm on the foothills in the east, rising to 1300 mm on the hill tops in this part. Except for the rainfall variations in the high hills, there is a general decrease of rainfall from west to east and from north to south. A large part of the study area receives less than 1200 mm of rainfall a year with the Kiambu area receiving the highest. Outside the forested zones located on the highest hills and in the areas to the north west, rainfall reliability is low.

The potential evapotranspiration is higher than the annual precipitation for most of the area especially that covered by the Precambrian metamorphic rocks, where the crystalline rocks have little water holding capacity. Daily sunshine hours are above 9 hours for most of the area making the area comfortably warm throughout the year. However, there is a marked hot spell during January to

February and a cold spell in the month of July when temperatures are sometimes below 18^{o}C.

1.2.4 Physiography

The physiography of the area vary greatly over the area. The southern and eastern parts of the area is characterized by the high hill masses of Ilemelepo (2156 m), Ngoragaishi, Iveti (2125 m), Kilungu (1934 m), Mbooni (1939 m), Kiima Kiu (2018m), Mbatini (1809 m), Kalama (2006 m), Mua (2072 m) and Kanzalu (1828 m). Except for the Ilemelepo and Mua Hills which have rounded spurs, the others form isolated high hill masses with steep often deeply dissected margins. The rocks forming the hills are mainly granitic or micaceous gneisses of Precambrian age.

The hills are separated by extensive areas of ridges and valleys with dendritic drainage pattern. These are formed of a variety of gneisses of the Precambrian metamorphic rocks, intruded by a small number of basic intrusives mainly basaltic intrusives. The intrusives form the Kalembwani and Muaani (1409 m) Hills.

The western half of the area is characterized by flat lava plains. These are located to the south and east of Nairobi. The expanse of the plains is broken by a number of hill masses and tors. These stand conspicuously (300-600 m) above the plains. These hill crests, Lukenya (1837 m), Kongeni (1567 m), Matuu, Koma Rock (1603 m), Waami (1921 m), Kyamutheke (1912 m) and Kyumbi (1805 m) are composed of mainly granitoid and biotite gneisses of the Precambrian age. The plains especially the Kaputei Plains are cut by shallow dendritic flowing drainage river lines. In the far west of the plains, the volcanic hills of Embetera (2022 m), Endoinyo Narok (2026 m) and Ngong Hills (2460 m) form higher grounds. Of prominence are the Ngong Hills that rise 660 m above the plain. They are situated just on the edge of the Rift Valley and to their east and south fault scarps are present. Both parallel and dendritic drainage patterns are present here.

To the north and west of Nairobi, the plains break into a series of parallel ridges oriented south easterly and separated by winding valleys. Here the land slopes gently to the north west and is composed mainly of Tertiary volcanics. Exposures of Pleistocene volcanics are also present.

The Yatta Plateau to the north east of the area forms a long narrow plateau striking in a N 45^{o}W direction. The plateau extends further into the surrounding area. It has gentle depressions at its top and is strongly dissected along its margin. The plateau capping the Precambrian metamorphic rocks is a Tertiary phonolite lava.

1.2.5 Vegetation

Forests cover the upper reaches of Iveti, Kangundo, Mango, Uuni, Tulimani, Mbooni, Muumandu and Kilungu Hills. These hills receive an average rainfall of over 1500 mm during the long rain season (March to May). The vegetation takes various forms; clumped trees in grassland areas of the foothills to scrub or thicket at the valley bottoms. Locally forests are located on steep slopes giving way to cultivated forests of eucalyptus and wattle trees at the hill tops.

The 1500 mm rainfall is also registered in the north western end of the area. Much of the forest here, except the Kiambu, Karura, Dagoretti, Ololua and Ngong forests, has been cleared for cultivation. Despite large scale farming especially of coffee, small scale mixed farming is practiced and crops such as maize, beans, bananas, arrowroot yams, and napier grass are cultivated. At the valley bottoms and depressions found in this area, swamp grassland and wet grassland are found respectively.

Evergreen and semi-deciduous bushland cover large areas especially along the stream valleys and the footslopes of many of the hills. This type of vegetation is also continued in the 750-900 mm rainfall zone. Grassland, including wooded grassland, covers the plains. Here riverine forests are occasionally found along the drainage lines and river valleys. The grassland is mainly combretum savanna mainly grass with scattered low acacia trees (acacia drepanolobium). These cover the Athi and Kaputei plains. The wooded grassland and scrub is located mainly in the areas bordering the volcanic terrain.

1.2.6 Geology

1.2.6.1 Precambrian Metamorphic Rocks

The oldest rocks exposed in the area form part of the late Precambrian metamorphic rocks of the Mozambique Belt in Kenya. Age determination on the Precambrian metamorphic rocks show that the metamorphism occurred between 450 and 650 million years ago (Cahen and Snelling, 1966). The nature of the original sedimentary beds is not immediately apparent, though a study of the various metamorphic mineral assemblages provides evidence not only of the origin of the rocks but also of the temperature and pressure conditions that prevailed during metamorphism (Baker, 1954; Fairburn 1963). The commonest rocks are gneisses and schists derived from muds, sandy clays and a variety of impure sandstones and limestones. Purer sandstones present in original succession were completely recrystallized to form bands of resistant quartzites. Limestones underwent similar drastic change resulting in their transformation to marble.

Complicated folding and contortion of various beds is present. There is a tendency for the metamorphosed sedimentary rocks to adopt the appearance and composition of granites raising the problem of distinction between granitized sediments (granitoid gneisses) and intrusive igneous rocks (granites). Baker (1954), Jourbert (1957), Fairburn (1963), and Mathu (1980) have reported the presence of widespread schists, migmatites and granitoid gneisses. The presence of these rocks suggests the various stages of granitization process.

Precambrian intrusive rocks are the dark basic igneous rocks showing the effect of regional metamorphism. They are represented by metadolerites that form the Ol Donyo Sabuk Mountain, located to the north east edge of the area. Plagioclase amphibolites intrusives are not uncommon.

The metamorphic rocks are exposed in the eastern and southern parts of the area. Most of the hills in the eastern parts of the area are formed of granitoid gneisses, the main features being the Kanzalu Range and Kangundo Hills, the Mua, Iveti and Mbooni Hills, the Kalama, Iuani, Muumandu Range and the Uvete and Mbatini Hills.

Quartz-feldspar gneisses are extensively developed in the southern parts of the area. They are poorly exposed and form no prominent features. Bands and lenses of marble have been mapped (Baker, 1954 and Matheson, 1966) in this part, with the most prominent being, together with quartzites, that which form the Ilemelepo Hills. The other high hill masses around Enkorika are composed of augen gneisses. Many of the gneisses exposed in river beds occur as slabs or blocks. Muscovite-biotite gneisses occur in numerous places, but they are well developed in the

Kilungu Hills. The biotite gneiss occurrence in the north east are capped by Tertiary phonolite of the Yatta Plateau.

1.2.6.2 Tertiary Volcanics

There are widespread Tertiary volcanic occurrences in the western parts of the area. The earliest lava flow is the Kapiti Phonolite, that flowed south eastwards, across the eroded sub-Miocene surface from the edge of the newly formed Rift Valley (Baker, et al 1971; Baker, et al 1972; Gregory, 1896; Matheson, 1966). Observations at the edge of the lava sheet give the impression that the phonolite flowed across a gently sloping nearly flat surface (Matheson, 1966). However, within the sheet, in some places, the phonolite is very thick as is evident in a quarry south of Athi River, locality K79. In other localities it is very thin or absent all together as is indicated at locality K65 south of Isinya (see Plate 12). Such information point to uneven nature of the pre-lava surface.

A similar lava to the Kapiti Phonolite caps the Yatta Plateau, which extends well beyond the present area. Several theories have been advanced to explain the occurrence of phonolite on the Yatta Plateau. Gregory (1921), Schoeman (1948) and Sanders (1963) consider the flow as a remnant of a formally more extensive lava flow; Walsh (1963) suggests a flow down an old valley; Dodson (1953) favours an origin by fissure eruption along the length of the plateau. Fairburn (1963) advances the theory of a large sheet flow. More recently Chorowicz et al (1988) considers the Yatta Phonolite as having arisen from a fissure flow resulting from a transform fault that is part of the larger Aswa Lineament (Aswa Transform Fault).

The Kapiti Phonolite and the phonolite of the Yatta Plateau is a dark grey to black lava bearing prominent pale feldspar (anorthoclase) phenocrysts, 2 to 7 cm long, together with waxy looking crystals of nepheline about 1 cm across. Vesicles are often filled with red or yellowish silica or with zeolites and calcite.

The Kapiti Phonolite is overlain by pyroclastic rocks with interbedded lacustrine sediments, the Athi Tuffs and Lake Beds, especially around Athi River. In the west and towards the south, the phonolite is directly overlain by agglomerates (Ol Doinyo Narok Agglomerates) which grade into coarse, pale agglomeratic tuff towards the north. In the northern parts the Kapiti Phonolite is overlain by a pale bluish fine grained tuff containing glassy fragments and occasional feldspar crystals. This tuff is often referred to as Nairobi blue stone or Kerichwa Valley Tuff.

To the west of Athi River, the Athi Tuffs and Lake Beds are overlain by both the Mbagathi Trachytes and Nairobi Phonolite. The Nairobi Phonolite differ from Kapiti Phonolite in containing less conspicuous feldspar crystals and smaller nephelines. Small flakes of biotite are sometimes present. A prominent scarp marks the eastern and southern edges of the Nairobi Phonolite lava sheet.

A variety of basic lavas mainly dense black nephelines containing prominent pyroxene phenocrysts together with basanites, tephrites and phonolitic varieties form the Ngong Hills. The Nairobi Trachytes form a discontinuous outcrop north and west of the city. It is separated by the Kerichwa Valley tuffs. To the north west it is overlain by the Limuru, Tigoni and Kiambu Trachytes of Pleistocene age. Margins of the Nairobi trachytes are frequently marked by strong topographic relief, an example being the scarp bordering the hill area immediately west of the city centre. The Nairobi Trachyte is a pale grey mottled lava, its fresh surfaces have a glistening appearance caused by numerous, tiny feldspar crystals. Lavas of the Olorgesailie volcanic series mainly Olorgesailie Nepheline and Olorgesailie Biotite Phonolite together with Ol Esayeiti Biotite Phonolite occur in the western margin of the area.

1.2.6.3 Pleistocene and Recent Volcanic Rocks

Pleistocene and Recent volcanic rocks are mainly confined to the floor and shoulders of the Rift Valley in the adjacent area to the west. However, small exposures of Pleistocene trachytes, the Limuru, Tigoni and Kiambu Trachytes, are exposed north west of Nairobi. Here they obscure the earlier volcanics.

Olivine basalts and agglomerates of volcanic vents near Kima in the south east of the area are an extension of a field of Lower Pleistocene basanites and olivine basalts of the Simba area. Prominent volcanic features of this type include the volcanic cones of Kalembwani and Muaani Hills. Recent alluvial deposits are not uncommon in the flood plains of most of the rivers especially in the south east.

1.2.6.4 Soils

The wide variation in climate, geology and topography are reflected in the large number of soil types which can be found in the area. The soils vary from dark friable clays, to red and strongly brown clays with laterite horizon in the area north west of Nairobi. These are mainly fertile, deep volcanic soils suitable for agriculture. Just south west of Nairobi the soils are dark red friable clays and grayish brown mottled clays.

In the plains to the south and east of Nairobi, the soils are mainly dark grey to brown clay loam to dark clays of varying depths in the Athi Plains. This change to dark grey to black cracking clay over nodular calcium carbonate or tuff. These soils are seasonally water logged especially in the Kaputei Plains.

In the metamorphic terrain to the east, on the high hill masses and the south eastern area, the soils are dark red friable clays, yellow red sandy clay loams, and shallow stony soils with rock outcrop. Quartz stones can be found locally with weathered gneisses beneath. On the footslopes of the hill masses the soils are grey compact mottled plastic sandy loam with angular quartz gravel. East of Kanzalu Range, brown to yellow red clay loam with laterite horizon is predominant.

Lava boulders along the edges of phonolite lava flows (Plate 11); stony debris rock outcrops in several stream valleys (Plate 13 (c)) and some hill slopes; sands in river valleys (Plate 13 (d)) occur in several localities.

1.2.7 Structures

1.2.7.1 Folds

Major recumbent folds with N.E.-S.W. axial trend and a number of minor cross structures trending slightly west of north, can be recognized in the Precambrian rocks near Kajiado. In the east of the area these folds pass into complicated concentric structures especially around the granitoid gneiss domes of Uvete, Mbooni and Iveti Hills.

1.2.7.2 Faults and Other Linears

The main faults in the region are confined to the western margin which is on the shoulder of the Rift Valley. This part is characterized by complex N-S structural patterns associated with the Eastern (or Gregory) Rift Valley. (Joubert, 1957; Matheson 1966). The linear structures in the Precambrian Mozambique Belt System correspond to the strike of the Precambrian metamorphic grain trending mainly in NW-SE direction. The foliation trend parallel the original bedding plains of the sedimentary rocks from which the metamorphic rocks were derived and therefore parallel boundaries between distinct rock types, mineralogical banding and preferred orientation of flaky minerals.

CHAPTER TWO

2. LITERATURE REVIEW

2.1 The Spacecrafts and Imaging Systems

The present study was limited to the interpretation of Landsat imagery and imagery from the Space Shuttle Mission. The first Landsat satellite, originally known as ERTS-1 (Earth Resources Technology Satellite One) was launched on 23 July 1972 and continued functioning until 1979. Subsequent satellites, Landsat-2, 3, 4 and 5 were launched on 22 January 1975, 5 March 1978, 6 July 1982 and 1 March 1984, respectively. The Space Shuttle Mission is a manned Space-craft that has been operational in the 1980s and still operating (1990).

Each Landsat satellite carries an imaging system that views the earth in certain spectral bands. The sensors on board Landsat 1, 2 and 3 were the Return Beam Vidicon (RBV) Camera that viewed the earth in three spectral bands; band 1 (0.475-0.575 μm - green), band 2 (0.580-0.680 μm - Red) and band 3 (0.690-0.830 μm- infrared). The other imaging system was the Multispectral Scanner (MSS) that viewed the earth in four spectral bands; band 4 (0.5-0.6 μm - green) band 5 (0.6-0.7 μm- orange), band 6 (0.7 - 0.8 μm - infrared), and band 7 (0.8 - 1.1 μm - infrared). (Lillesand and Keifer, 1979).

With the advent of the other Landsat satellites, an improvement was made on the bands and new imaging systems added. In particular a Thematic Mapper (TM) imaging system was added to the Landsat 4 and 5 satellites. The TM system had channels for seven spectral bands imaging in the region; band 1 (0.45-0.52 μm - blue), band 2 (0.52-0.60 μm - green), band 3 (0.63-0.69 μm - red), band 4 (0.76-0.90 μm - near infrared), band 5 (1.55-1.75 μm- middle infrared), band 6 (10.4-12.5 μm - thermal) and band 7 (2.08-2.35 μm - far infrared). (Lo, 1986).

A comparison of the bands utilized by the imaging systems in the Landsat satellites in the various spectral bands is shown in table 1. According to the theory of wave propagation, the sun radiates infinite energy and as shown in the table, only a small part of the electromagnetic spectrum is utilized by the imaging systems. This is dictated by the type of sensors available.

The imaging systems in the Space Shuttle Mission was the Modular Optical multispectral Scanner (MOMS-01) System for the particular scene used in the present study. MOMS system imaged in two bands, band 1 (0.575- 0.625 μm - Red) and band 2 (0.825-0.975 μm - infrared). The field of view of the system was 138 x 92 km with nominal instantaneous field of view (resolution) of 20 x 20 m cell.

The orbit of Landsat-5 is sun synchronous at 705 km with the orbit inclined at 98.2°, and the equator passage time

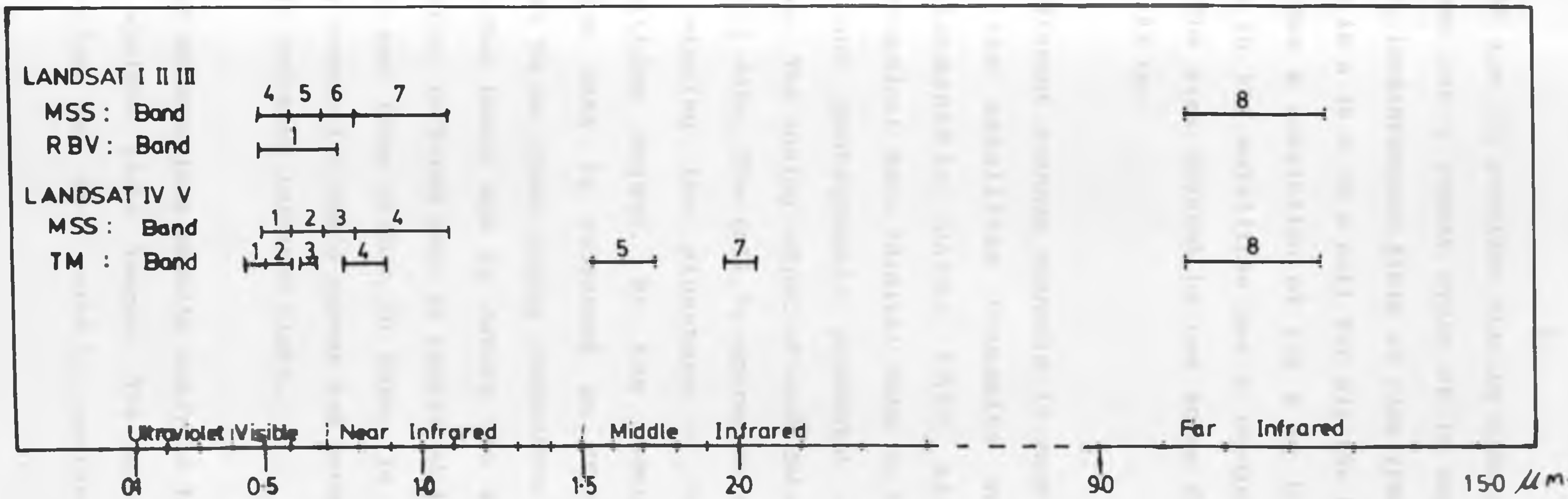


TABLE 1: Comparison of the spectral bands utilized by the various imaging systems of the landsat satellites (compiled from Short (1982) and Lo (1986)).

at 9.45 a.m. It provides side by side possible overlap of 7.6% and has a repeat cycle of 16 days (Lo, 1986). The nominal instantaneous field of view (resolution) in the TM system is a 30 x 30 m cell for all the bands except band 6 which has a resolution of 120 m by 120 m cell. The MSS system in the satellites has a resolution of 79 x 79 m cell. The area covered by one scene for both systems is 185 x 185 km.

The different scanner channels in each imaging system on board the satellites transmits satellite data as electromagnetic waves that are converted to electro-optical data (digital data on computer compatible tapes and photographic products) at the receiving stations. The analog output of each detector is encoded as a digital data. The cell is stored as a pixel on a given line, storing the signature of the reflecting or transmitting object. At the receiving station the satellite data is recreated as "false-colour" images referred to as false colour composites (FCC). This is to enable the human eye to detect the signatures. In the recreation, infrared data is recreated in red, true red in yellow, and true yellow in blue. In these recreation, healthy vegetation would appear red because its chlorophyl strongly reflects infrared light.

Infrared observations permits analysis that cannot be made from visible light images. The spectral and spatial information on the earth's surface available for interpretation is expressed in landform development (geomorphology), drainage density and pattern and vegetation. Variations of vegetation may be related to the health of growing crops which is affected by drought, disease, and surface rock types. Geomorphic development is a consequence of internal and external earth processes, that is recorded on the surface configuration of the area. The drainage density and pattern of an area is directly related to geomorphology of an area and therefore indirectly to the geology of the area.

Processing of digital data on computer compatible tapes (CCT) employ greater control and flexibility of the data. In these forms more data is often available than can be displayed and analyzed in a single picture. This can greatly increase the accuracy of the maps. Enhancement techniques that are employed to both computer and photographic products explained in <u>Appendix 1</u>

2.1.1 <u>Spectral reflectance</u>

Images intercepting land areas are characterized by "strong variance". There are numerous targets such as soils, rocks, vegetation (forests, grassland, cropped land), land occupied or not occupied by man, urban zones, rivers and lakes. These terrestrial targets are recorded on the photographic image as a spectral reflectance:-

$$\text{Spectral reflectance} = \frac{\text{Reflected energy} \times 100}{\text{Incident energy}}$$

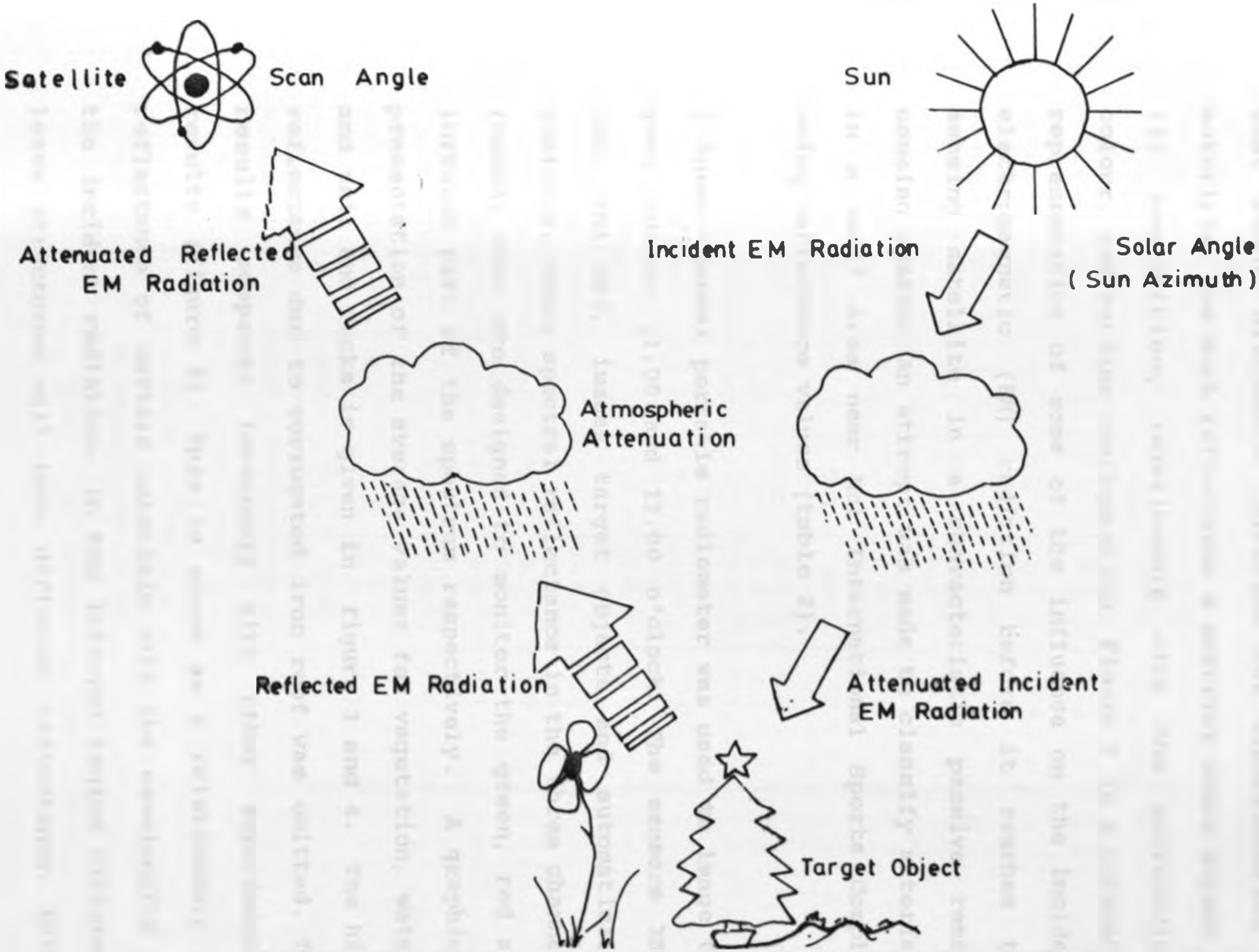


Figure 2- Schematic representation of some of the influences on the incident electromagnetic (EM) radiation before it reaches the sensing satellite in a passive remote sensing system (modified from Lillesand and Kiefer ([redacted]).

Spectral reflectance is a consequence of the chemistry and structure of material modified by environmental factors and physical conditions of material (Siegel and Gillespie, 1980). It is characteristic of materials and therefore the most useful diagnostic criterion for discrimination of materials. How much reflectance a material shows depend on its composition, relationship with the surrounding, colour, and surface configuration. Figure 2 is a schematic representation of some of the influence on the incident electromagnetic (EM) radiation before it reaches the sensing satellite in a characteristic passive remote sensing system. An attempt was made to classify materials in a small area near Moi International Sports Complex using reflectance values (table 2).

A three channel portable radiometer was used to image the area between 11.00 and 12.00 o'clock. The sensors XS1, XS2, and XS3, images target objects and automatically averages, their spectral reflectance in the three channels (bands) that are designed to monitor the green, red and infrared part of the spectrum respectively. A graphical presentation of the average values for vegetation, water, and soil and rocks is given in figure 3 and 4. The high reflectance due to corrugated iron roof was omitted. The results compares favourably with other experimental results (figure 5). This is shown as a relationship of reflectance of certain materials with the wavelengths of the incident radiation. In the infrared region different leave structures will have different reflectance. Water absorbs all infrared light and silty water, will reflect a little energy to space. Each curve represents the spectral signature of the material.

Table 2 - Reflectance values as measured in the three sensors.

Target Object	Reflectance in Percentage XS 1 (GREEN)	XS 2 (RED)	XS 3 (INFRARED)
Green grass	6.4	5.4	27.7
Herbaceous plants			
- green leaves	5.3	2.7	45.4
- red leaves	3.4	7.9	45.7
Bougainvillea plants			
- bright red flowers	4.4	11.5	47.3
- red flowers	4.8	9.4	30.6
- light purple flowers	13.0	18.4	50.2
- green leaves	7.0	4.0	42.4
Watered grass	4.2	4.4	15.5
Average for vegetation	6.2	8.0	40.6
Deep turbid running water	6.1	6.1	1.5
Shallow durbid running water	5.8	6.4	4.1
Clear shallow standing water	1.7	2.1	2.3
Clear shallow running water	3.3	4.5	5.2
Average for water	4.2	4.8	3.3
Ash (burnt grass)	3.7	3.8	4.5
Laterite soil	4.5	7.2	9.1
Laterite surfaced road	6.6	10.3	13.3
Wet tarred surface (road)	3.5	4.2	4.1
Wet tarred surface shadow	4.5	5.7	3.6
Dry tarred surface (road)	7.0	8.8	9.9
Weathered trachytic tuff	6.0	9.4	12.3
Trachytic tuff	15.5	15.1	14.0
Weathered trachyte	5.6	7.9	13.8
Trachyte	7.1	9.2	10.5
Bright polished surface			
(corrugated iron roof)	75.2	61.0	66.7
Average for soil and rocks	6.7	8.6	10.1

Note that the imaging bands are:

XS1 = 0.5 - 0.59 μm (green)

XS2 = 0.61 - 0.68 μm (red)

XS3 = 0.79 - 0.89 μm (infra-red)

(Field measurements, Dec. 1988)

Figure 3.

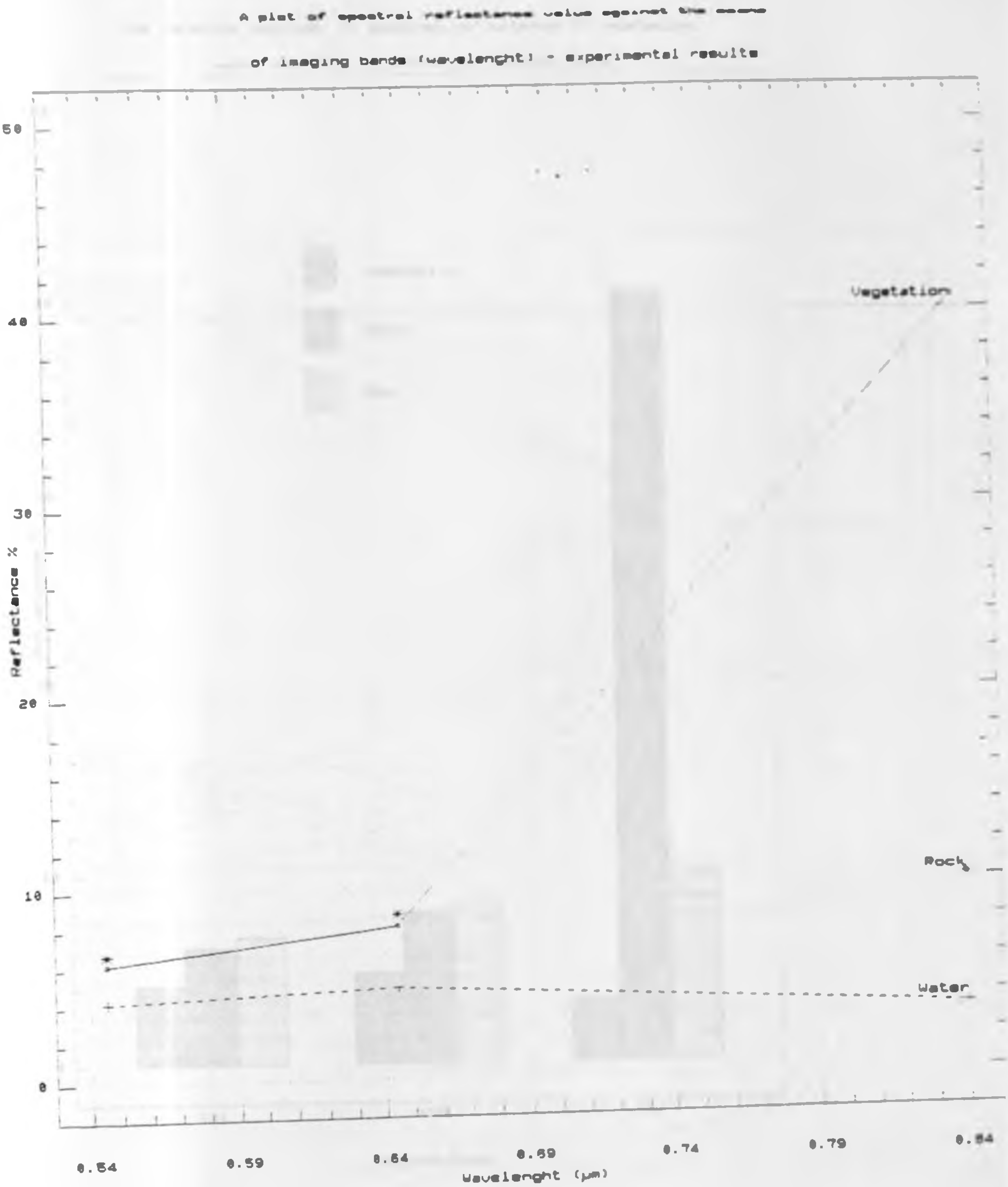
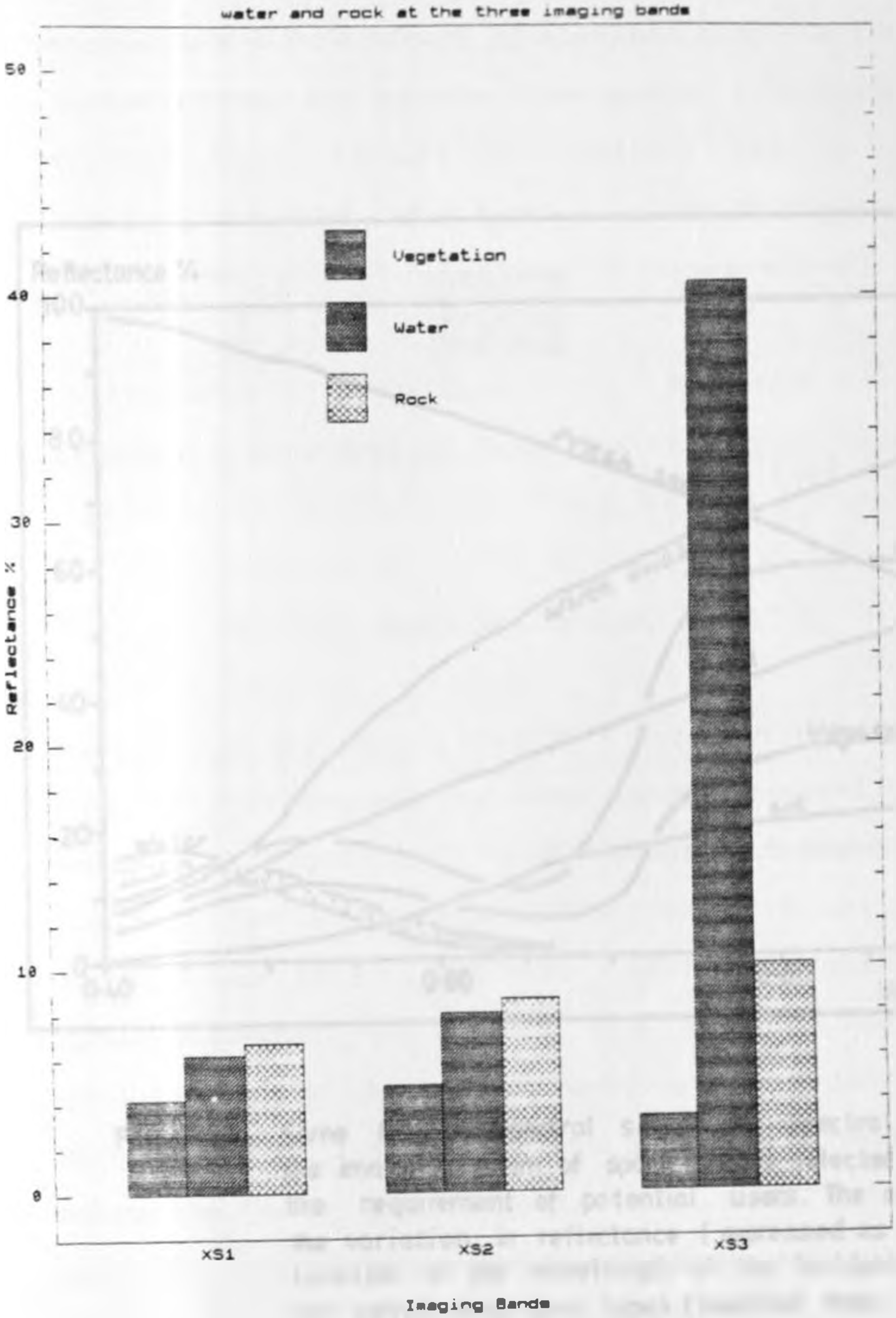

A plot of spectral reflectance value against the means
of imaging bands (wavelenght) - experimental results
Reflectance %
0
10
20
30
40
50
Vegetation
Rock
Water
0.54
0.59
0.64
0.69
0.74
0.79
0.84
Wavelenght (μm)

Figure 4.

The relative contrast in spectral reflectance of vegetation, water and rock at the three imaging bands



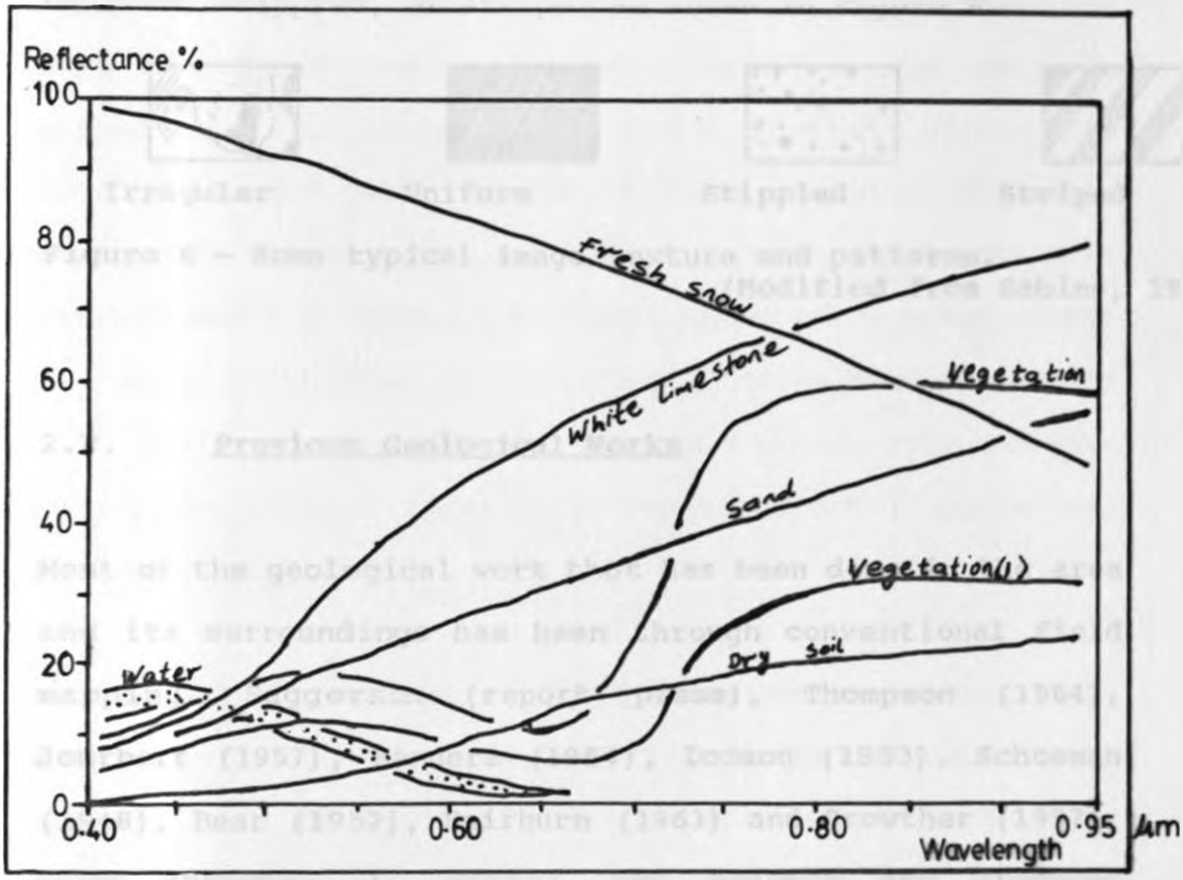
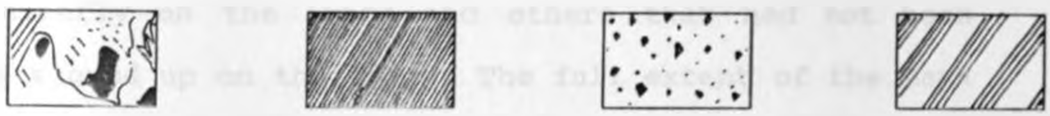


FIGURE 5 : Some typical spectral signatures. Spectral bands in the imaging system of spacecraft are selected to meet the requirement of potential users. The curves show the variation in reflectance (expressed as %) as a function of the wavelength of the incident radiation for certain land cover types (modified from Short (1982)).

NB: vegetation (1) refers to low chlorophyll vegetation.

Spectral reflectivity is expressed in images as photographic tone or colour. This is coupled with size, shape, and shadow effect of elevated features togetherwith image texture and pattern when making interpretation. The typical image texture and pattern may be irregular, uniform, stippled, or striped as shown in figure 6.



Irregular Uniform Stippled Striped

Figure 6 - Some typical image texture and patterns. (Modified from Sabins, 1978

2.2. Previous Geological Works

Most of the geological work that has been done in the area and its surroundings has been through conventional field mapping. Saggerson (report press), Thompson (1964), Jourbert (1957), Sanders (1954), Dodson (1953), Schoeman (1948), Bear (1952), Fairburn (1963) and Crowther (1957), have reported in detail the geology and produced geological maps of the area and its surrounding. Distinct lithologies of the Precambrian metamorphic rocks and the volcanics have been mapped. They have indicated and analyzed both minor and major structures especially folds, faults, foliation, joints and lineations. Intrusives are also noted. Through the use of the conventional maps exploitation of natural resources has been pre-emptied for many parts.

Reconnaissance mapping from images for preliminary geologic mapping programmes for the Kenyan situation has been reported. Miller (1975) describes an important use of Landsat images in helping to define a large sedimentary basin in eastern Kenya. He could identify previously mapped features on Landsat images. He saw several features more clearly on the image and others that had not been mapped showed up on the image. The full extent of the Lagh Bogal lineament was identified as a sub-surface fault. Norconsult Engineers in collaboration with IBM/Norway have carried out a project in northern Kenya and Southern Sudan and have shown how remote sensing techniques, combined with field measurements can play a central role in data collection process especially for transport planning and highway engineering.

Other geologic mapping studies from remote sensed data have been done. Bhattarai (1983), Sabins (1978), Goetz (1976), have shown that the use of Landsat images for mineral exploration lean heavily toward structural interpretations and particularly the mapping of linear features or lineaments. Mineralized zones are related to local and regional fracture systems. Intersection fractures are often associated with mining districts and the synoptic view recorded by Landsat facilitates the statistical correlation on a regional basis. Lineament system can be used to extrapolate from known mining districts, into less well prospected areas.

Fillippone (1986) indicates that long lineaments are related to deep seated basement faulting, the longer they are the more involved are the basement rocks and the continental granitic layer. Correlation of lineaments to known geological, oil and gas fields, minerals, faults or volcanic activity are areas where Landsat data can be put into. Fillippone (1986) also gives an account of the use of enhanced, filtered, transformed and statistically analyzed Landsat data in grey tones and false colour to discover ways to derive more definitive information. Kowalik et al (1987) have used digital image processing of aeromagnetic data in conjunction with Landsat multispectral scanner (MSS) image for structural interpretation. Goetz et al 1975 has shown that features seen on satellite images and airborne and ground geophysical measurements frequently coincide, lending evidence to the assertion that sub-surface features are expressed at the surface and can be detected if proper perspective is used.

Sabins (1978), and Hunt (1977), have shown that the reflectance of rocks and minerals in the wavelength regions 0.5 - 1.1μm is dominated by the quantity and oxidation state of iron. Sabins (1978), indicates that hydrothermal alterations are marked by distinctive assemblages of secondary minerals that are laterally and vertically zoned with respect to the ore body. When exposed through erosion and uplift, sulphide minerals weather to form an oxidized surface deposit called a gossan. In areas of less than 30% vegetation cover, observation of small rings and specific reflectivity on Landsat image is a pointer to the alterations.

Ilyin et al (1983) have given an account of the application of space image to mineral exploration. They give special emphasis to circular features observed on small scale and low resolution pictures, from meteor 25 satellite, within the Precambrian terrain of the Alden and Baltic Shields in the USSR. The significance of the circular features especially to metallogenic, oil-gas field exploration and the study of the recent tectonics is also discussed.

Plants have variable requirements and tolerances that depend on the full range of environmental factors. In particular, climate and topographic relief greatly affect the availability of nutrients. The plant community at a particular area is therefore a function of the local geology. Geological structures for example are enhanced by anomalous vegetation pattern, reflecting the higher moisture content found along fractures and fault zones due to their structural control of ground water. Vegetation, then, can be mapped as an indicator of all the other factors, a subject of Indicator Geobotany. Raines and Conney in Siegal and Gillespie (1980) have devised a method of getting geological information from vegetation studies. They describe remote sensing aspects which involve study of spectral reflectance in order to define geologic differences of landscapes. D'Hoore (1977) found that variation in soil constituents and characteristics directly influence plant canopy development and hence their spectral signatures. Climate variation influences plant phenological behaviour. These two factors are amenable to study employing satellite imagery.

Cole et al. (1974), using Landsat (MSS) and aerial photography, mapped plant communities which correspond to specific geologic formations. Labovitz et al. (1983) have investigated the use of remote sensing data to show that geobotanical anomalies are associated with mineral deposits.

Spectral signatures (image tone or colour),especially observations in infrared can be exploited in delineating remote sensing units. Other "clues" are found in topographic expressions, structural relationships, outcrop patterns and contextual associations in deciding on the identity of distinct remote sensing units (Curran, 1985; Harris, 1987). The mapping of remote sensing units then,provides a mechanism of indirectly understanding the geological processes in an area.

CHAPTER THREE

3. MATERIALS AND METHODS

3.1 Topographic Maps

The topographic map used for the study was the Nairobi Sheet SA-37-5, Edition 5-SK, at a scale of 1:250,000. This type of map has been generated from medium scale aerial photographs and field surveys. Details on the map include colour shading to signify the elevation, contour lines, standard symbols for vegetation cover types and certain landforms such as scarps, plains, and hills. Cultural information such as built up areas, roads and railways are shown. Rivers, seasonal or otherwise are also indicated.

The base map used for compiling the geological data was prepared from the topographic map. The area was delineated and enlarged to a scale of 1:125,000 using Kargl Reflecting Projector. The necessary topographic information was traced out onto a drafting film. The symbols for the map were redesigned and a graphical scale line constructed. Place names and graticule values were stencilled, while free hand lettering of river names was done. Other texts such as the legend, spot-heights and hill names were typeset on Revoprint Film using the Alpha Comp Type-setting Machine. The product from the type-setter was developed to obtain a positive text on film. The negative contacted out of the positive film was exposed onto a stripper (stripping) film to form a positive stripper film. Waxing of the stripper film with the alpha-numeric characters was made and the text was ready for sticking onto the map. Any number of dye-line prints could be made from the resulting map after all the geologic objects had been included. At the scale of 1:125,000, the base map was at the same scale as the working image.

3.2 A Land System Atlas of Western Kenya

In the atlas, landforms, soils, geology, surfacial materials, hydrology, landcover-type and climate are described in general terms. Scott et al (1971) has divided the area into thirteen different land systems (**figure 8**). He gives a short description of each land system with their characterizing features. At a scale of 1:500,000, the land system units of Scott et al (1971) were compared with those identified from landsat MSS black and white (**Plate 1**) and false colour imagery. The delineated boundaries from the imagery are shown in **figure 7**.

3.3 Previous Geological Works

The reports (Matheson, 1966; Baker, 1954; Saggerson, (report in publication); Fairburn, 1963) cover 30 minute quadrangles. They describe in substantive detail the surface and subsurface geology of the study area. Included in this description is the composition and origin of rock types, geological structure and the general geological history of the area. The economic minerals of the area are also described. Accompanying each report is a coloured geological map at a scale of 1:125,000 with a vertical cross section diagram.

Adjacent quadrangles of these maps show discrepancies in unit boundaries and structural continuity. This is corrected. The interpreted remote sensing units from satellite imagery were compared to the lithologic units shown in the geological maps. The naming of the remote sensing units was based on the units shown in the geological reports and maps of the area, although supplemented with field mapping.

3.4 Rainfall Data and Agricultural Information

The rainfall figures and information on general hydrology of the area was obtained from the Ministry of Water

Development (personal communication with the Director of Water Development). Detailed information about hydrological manifestations in the area west of Nairobi was available. Agricultural potential is feasible in the area north and west of Nairobi. The black cotton plains of Embakasi, Athi and Kaputei have been set aside for ranching and wildlife conservation. In the northern parts of the plains, a little cultivation of sisal is done. Little cultivation is done in the Precambrian metamorphic terrain except where there is ample rainfall and a deep soil development especially on the highest hills.

The rainfall and agricultural information was used to delineate the agricultural zones from non-agricultural zones thus enabling the identification of the settlement patterns from the satellite imagery. The settlement pattern is indirectly related to the geology of the area.

3.5 Remote Sensed Data.

9 x 9 inch positive transparencies were prepared after studies of 70 x 70 mm individual band film transparencies were made in the spectral data series 70 mm - Colour Additive Viewer (CAV). The optical instrument was capable of enhancing features in the imagery. Using the CAV, individual bands were composited using two, three or four

bands. This was done in false colours, or assimilated natural colours and in black and white, depending on which combination gave the most contrasting features. After the right colours and combination of bands were determined, and the best images selected, the 9 x 9 inch colour composite positive film transparencies were prepared by mixing individual bands using the CHROMEGA-200 or CHROMEGA-D enlarger with colour head. The 9 x 9 inch frames were re-used on a suitable enlarger and the image

Table 3: A Summary of the Satellite Data used for the Study

Frame and Date	Print Scale	Type of Print	Bands Composited and colours
Landsat-5-TM 27 Nov. 1985	1:125,000	CIBA Colour Trans-lucent film	False colour composite (FCC), bands 2-yellow, 3-red, 4-blue
Landsat-5-TM 2 Sept. 1986	1:250,000	CIBA colour paper-print	FCC bands 2-yellow, 3-red, 4-blue
Landsat-3-MSS 11 Feb. 1978	1:500,000	KODAK continuous tone paper print	black and white band 5
Landsat-3-MSS 17 Feb. 1980	1:500,000	CIBA colour paper print	FCC bands 4-yellow, 5-red 7-blue
Landsat-3-MSS 24 Feb. 1978	1:250,000	CIBA colour paper print	FCC bands 4-yellow, 5-red 7-blue
Space Shuttle MOMS-1 27 July 1985	1:250,000	KODAK continuous tone paper print	black and white, bands 1 and 2

projected to make any number of paper prints or films at the desired scale. Six frames and three scales were selected for the study.

The desired area was selected and positioned in the enlarger. The scale on the enlarger was set to the required scale and the colours evaluated. After the test exposures and the right filtration was set, the working prints were processed (Table 3).

In working with all the images discussed in table 3, certain geologic features were located in some images and multitemporal changes were compared. The advantage of working with the CIBA translucent film other than the paper prints was that the light table was used to study the image, which greatly enhanced geologic features.

Visual interpretation of the photographic products was made. Remote sensing unit boundaries were delineated on the basis of colour hue, tone, texture, drainage pattern, geomorphic expressions and characteristics, settlement patterns and other spectral patterns related to vegetation distribution. The unit boundaries were traced out on transparent overlays (working transparencies). They were then compared to the existing geological maps and further interpretation made using topographic maps, the land system atlas and rainfall and agricultural information before field investigation was made.

3.6 Field Investigation

After delineations of remote sensed units on the imagery, adequate field ground truthing was necessary. Lithologic unit boundaries were mapped in the field by visiting the localities of unit boundaries interpreted from the imagery. Each lithologic unit was described and named in the field from hand specimens. Where there was a discrepancy between the interpreted lithological units and those shown on the geological maps, rock samples were taken for microscopic identification. Structural features were also verified in the field and their strike and trend measured whenever possible. The field information was compiled into the base map. Definitive transparencies were prepared from the working transparencies and corrected using the recorded field data and identified geological objects. The information was finally transferred onto the base map resulting in a synthetic geological map of the Nairobi-Kajiado-Machakos area.

CHAPTER FOUR

4. GEOLOGICAL INTERPRETATION

4.1 Introduction

Transparent overlays were prepared and registered together with the images. The study area was delineated by drawing the graticules and indicating the graticule values on the overlays. Six images were used to offset the effects of temporal changes. For each image two working transparencies were used, to track out drainage pattern and other linear geological features, and the other for distinct land units.

Visual interpretation was made on the basis of unifying factors such as colour hue, tone and image texture, and geometric shape, form and patterns and vegetation cover. Geomorphic features and structural patterns such as striations on the Precambrian metamorphic rocks, directly observed on the image were also used for mapping. A magnifying glass and a light table together with eye-shed colour filters were used on the transparent film print of the Landsat-5 TM image. The delineated remote sensing units and linear features were compared with the geological units and structural features contained in the previous geological reports and maps of the area.

The Land System units of Scott et al (1971), the topographic map and information on rainfall and agriculture were also considered in the interpretation. The topographic map was also used to compare the drainage pattern shown and that observed on the imagery.

In the eastern and southern parts of the area surface materials show a large spectral differences. The area displays significant differences in landforms and drainage pattern density (Plate 13). The vegetation cover is uniform for this area but differs markedly from that found in the western parts of the area. The varying resistance to weathering of rock units between the slopes is sharply reflected in the topography. On the ridges and valley slopes there is a slow rate of soil formation and sparse vegetation (Plate 15). Due to absence of ample rainfall, the weathering mantle is not excessively leached, therefore, soils closely resemble the composition of the underlying rock. This area yields the greatest amount of geologic information to remote sensing. Several ground distinguishable units with similar reflectance properties were mapped from the imagery.

In the western parts of the area, rocks are concealed under soil and vegetation. The surface configuration the relief, slope and general geomorphic expressions are poor, although scarps marking the edge of major lava flows are prominent on the images (Plates 2, 7, 10 and 11). The texture on the image and the drainage pattern were also considered in delineating the different remote sensing units in this part. The drainage pattern was directly related to geomorphology of the area and therefore to some extent, the geology of the area.

These factors were considered together with vegetation cover. Included was the extent of the natural vegetation i.e. indigenous plant communities found on the land and riverine vegetation, as opposed to cultivated vegetation such as hay fields or cropped land and cultivated forests. The location and shape of cultivated fields and their pattern and size in relation to the overall scene were mapped. The settlement pattern and associated transportation network, their relative density and arrangement were also mapped. They point to the presence of fertile soils, an indirect indicator of the type of underlying rock, and ample rainfall. This area has minimal rock exposures and the majority of discernable geological and geomorphological features are in the spectra of vegetation cover. The vegetation cover severely hinders visual interpretation of data for soil mapping and lithologic discrimination. These areas were discriminated for field check.

The extent of vegetation cover in certain localities reflected only the influence of topography, (Plates 14 and 16), relative rainfall (humidity), insolation, prevailing wind direction and the maturation stage of the floral community.

At a smaller scale of the satellite imagery, only important geological and geomorphological features were observed. The use of Landsat-3 MSS data at a scale of

1:500,000 was helpful in identifying the major lineament and drainage patterns and major geomorphological features and structures.

On the image, where geomorphological expression was good, a simplified geologic scheme (cross-section) of the lithostratigraphic units were drawn. These helped in identifying the lithologic units, their relative succession and thickness. The geologic features traced from the imagery included the lithologic which are a result of the intersection between lithologic surfaces and sharp discontinuities between lithologies. This is also expressed in geomorphology where soft rock shows easy erosion compared to hard rocks which stand out. A line of vegetation and colour contrast on the image may provide a lithologic boundary. Other geologic features traced out were lithologic units and dip and strike of rocks. Volcanic features were also traced out by observing the lobate patterns of lava flows, volcanic cones and craters. Linear features (e.g. faults) were also traced out by studying lines of vegetation, offset lithologic units and shadowing effects. Features observed were supplemented by field ground truthing to further identify the units before a synthetic map was drawn.

4.2 General Interpretation

The tonal contrast between vegetation of shaded and illuminated slopes was conveniently used for geomorphological evaluation. Western facing slopes are shaded. At the time of the day when the images were taken, around 9 a.m. local time, the sun azimuth is such that elevated features form a shadow to the west. Note is made here that lower sun angles are required to enhance subdued features. The shadow effect enhances the features. The eastern steps of the Rift Valley show up very clearly on the image as geomorphological feature representing step faulting that strikes in a north south direction. The faults are down-stepped to the west and appear as dark linear features on the image especially to the south west of Nairobi. In the Precambrian metamorphic terrain of the Mozambiquan Metamorphic Belt, most of the hills form a range or ridge striking in a near north-south direction. In particular, the Yatta Plateau Strike N.45^{o}W; the Kanzalu range N.27^{o}W; Mbanya, Kalema, and Muumandu Hills N.37^{o}W; Kiima Kiu, Lukenya and Mua Hills N-S. Other hills in this part such as Kilungu, Mbatini, Kilima Kyakatoni, Iluni, Kiima Kimwe, and Uvete form near circular massives. The hills were more distinct on the smaller scale images. They were easily delineated on Landsat-3 MSS black and white and FCC imagery and on the MOMS-01 image. After delineations of the hills a thorough examination was made on the Landsat-5 TM image.

The edges of lava flow when illuminated show a tonal contrast in vegetation, with the scarp bearing more vegetation than the surrounding area. On the image this appears as a lithologic trace mark which was used to map the edge of the lava flow (Plates 2, 7, 10 and 14). The edge of the flows were easily traceable for long distances without a break. In some localities for example the lobate edge of the Nairobi Phonolite lava flow, the lobate pattern was enhanced by the radial drainage pattern that is characteristic of this flow.

Evident on the images are clouds that appear fluffy and white with a black shadow to the west. The clouds appear white because they reflect most of the energy falling on them. The black shadow to the west is because of the sun azimuth at the time of the day when the satellite crosses over the area. The higher the cloud the further the shadow is from the cloud. Together, the cloud and its shadow obscure ground features making it impossible to make any interpretation where they cover.

In the Landsat-3 MSS image of 11th February 1976 (Plate 1), although in general a clear image another hindrance to visual interpretation is evident. A smoke cover has obscured the southern parts of the image. The origin of the fire causing the smoke is noted in the southern east of the image. A black scar (1) on the surface of land is developing. The direction of the wind blow is obvious, being marked by the trail of smoke that has formed the white feature running N.55^{o}W. Such a black mark created by fire, and similar to the ones appearing on the same image to the north west of the Nairobi National Park (2) can be confused for water bodies or other features. The use of several images for different years or different times of the same year helps offset such temporal changes. Note is made here that a study of temporal changes mainly environmental hazards such as forest fires, floods etc.

can be made from satellite images if it were possible to get repetitive image covering in the period of the hazard. Note is also made here that at the time the Landsat satellite passes over the study area, nearly always, the same parts of the area are covered by clouds.

In all the images, the featureless lava plains to the west (Plates 2 and 7), contrast markedly with the rugged Precambrian metamorphic terrain to the east and south (Plates 10, 14 and 16). The plains are grass- covered, broken only by riverine vegetation and scrub and woodland along the edge of the lava flows. In the north west the plain rises gently culminating in parallel south east running ridges separated by narrow winding streams. The featureless plain is occasionally broken by a few high hill masses rising 200-600 m above the plain. The hills except for the Ngong Hills are erosion remnants of the Precambrian metamorphic rocks standing above the general surface that is now covered by lava. The hills include Kongoni (1567 m), Koma Rock (1603 m), Matuu, Lukenya (1837 m) and Kyumbi (1805 m).

In rain regimes such as the north western parts of the area, there is a tendency for soils from different rock formations to become similar in maturity due to leaching. In the eastern areas where rainfall is minimal, the soil types have the same composition as the underlying rock types. Thus in this part the soil cover type and the vegetation cover have a direct bearing to the underlying rock. The remote sensing units interpreted from the image

Table 4 - Interpreted remote sensing units compared to the land system units of Scott et al. (1971)

Satellite Remote Sensing Units	Geomorphological Description of the Remote Sensing Units	Corresponding Land System Units	Geology	Vegetation
1	Parallel south east trending ridges separated by winding stream valleys. Covered by riverine vegetation. Dominated by small scale farming of mixed crop. Marked on image by stippled texture, indicative of small scale farming areas.	Kikuyu and Kiambu:- long narrow ridges separated by narrow winding valleys.	Pyroclastic rocks, mainly tuffs with occasional exposure of trachytes obscured by dark red clay soils.	Indigenous vegetation has totally been cleared for cultivation except small forests.
2 2'	Zone cultivated with coffee plantations. It is located at the confluence of many of the parallel streams to the west and also forms the foothills of Ngong Hills. The south easterly flowing streams are dominant.	Kiambu, Karen and Kahawa:- Varies from broad parallel ridges to extensive broad low undulations and gentle depressions; dissected by winding steep sided river valleys.	Volcanic rocks mainly trachytic tuffs and trachytes of Tertiary age.	Has been cleared for coffee plantations and small scale farming. Small scale forests of indigenous kind are noted.
2" 3 3"	Marked by low undulations with sparse streams. The streams change course to flow in a north easterly direction. Also marked on the image by a stippled texture of dark brown to grey areas in the FCC.	Kahawa:- Area of low broad undulations and gentle depressions dissected by winding steep sided flat bottomed valleys with occasional low hills on plain.	Rocks are trachytic tuffs with Kapiti Phonolite exposed at the Nairobi river. The rocks are concealed by red to strong brown clays with laterite horizon.	The area is cultivated or covered by grassland and scrub.

4 4' 4"	Formed of featureless plain characterized by mound topography and bordered along the east by a scarp-like edge marking edge of a lava flow. The lava edge can be traced to the Embakasi river that has eroded a wide valley that forms the northern boundary of 4'. The unit 4' is characterised by a radial drainage pattern marking the fan like Nairobi phonolite lava flow. The unit 4 is marked to the east by an edge of a lava flow and is characterized by a parallel drainage pattern. Towards the western end of the area, 4'' is noted. Here the flat plain breaks into relatively undulating plain with pinnate short drainage lines indicative of presence of hard rock. The area is characterized by grey blue areas of a smooth texture.	Embakasi:- Plains of low gradient with low hummocky micro-reliefs and small drainage lines transversed by radial or parallel river gorges. Locally the plains are fringed by an escarpment.	A variety of tuffs mainly agglomeratic tuffs, agglomerates and a variety of phonolite lava flows. The Nairobi Phonolite, Olorgesailie biotite-olivine-phonolite are conspicuous. Water deposited pyroclastics are exposed in some of the valleys. The rocks are overlain by a dark grey-black cracking clay that is slightly calcareous. Changing to yellow brown to yellow red friable clays overlying massive laterite or little weathered phonolite towards the west.	The vegetation is grassland savanna mainly grass with scattered low acacia trees (acacia drepanolobium). Riverine forest is also present
5 5' 5"	The unit 5"located west of Lukenya Hills is formed of gentle convex ridges and gentle side slopes flanking low intervulves. The plain marked by the unit 5 bear broad undulations that on the image appear as near circular or elongated patterns of white tone mainly a result of high reflec-	Athi:- Extensive low undulating plains with infrequent minor drainage lines and occasional rivers. The flood plains of the rivers are wide.	Kapiti Phonolite is exposed in the major rivers. It is overlain by a yellow/white tuff in the area around Athi River and in the northern parts a grey/blue tuff overlies it. A dark grey to black clay soil derived	Riverine forest of dense acacia (acacia Xanthophleae) and Savanna grassland

	tion from the bear surface during the dry season. A dendritic drainage pattern is evident with the minor drainage lines occupying the dark zones on the image. The rivers are marked by a dense vegetation that appear as a line of red on the FCC. The unit 5' has a marked absence of the broad low undulations it is relatively flat and dips gently to the north west.		from the poorly drained phonolites obscure the rocks and extend well into the Precambrian gneisses and overlies them. Calcium carbonate and tuffs underlay the soils.	with scattered low acacia (acacia drepanolobium). Sisal is cultivated west of Lukenya and food crops in the vicinity of Athi River.
6	Excluding the high hill masses the area is defined by the Eselenkat and Toroka rivers. The area is located in the south west and to the south of Konza-Toroka railway line. The rivers are clearly defined by vegetation or appear white due to high reflectance of the sand occupying their beds. The area appears dark brown to red in FCC and dark grey in black and white images. The surrounding ridge crests are yellow brown in the FCC. The ridges are flat to gently sloping.	**Maiyani Variant:-** An extensive area of low ridges and valleys with dendritic pattern. The ridges may have sharp crests or broad rounded crests.	A variety of gneisses of the Precambrian metamorphics mainly concealed by bare brown sandy loam and sandy clay loam. Sometimes dark reddish brown friable clays with a quartz stone line is present.	The vegetation is mainly acacia savanna along the northern margin and wooded-grassland towards the south. The woods include plants such as acacia seyal, solanum orondo and alanites aegyptiaca. A riverine vegetation is also present.

7	The unit form the high hill masses that are more elongated in a north-south direction than being circular. They are more or less marked by a very steep slope on the east or west margins. They are deeply dissected where the slope is moderately steep. The ridge crests are narrow and more or less rounded.	**Mbooni:-** Included are a number of isolated high hill masses with steep deeply dissected margin. The summit levels are at 1700 m-2100 m representing a Pre-Miocene erosion surface.
8 8'	The unit form the near circular high hill masses that are steep to very steep. The hills are strongly dissected by irregular drainage pattern due to rock outcrops. They form closely spaced elongated rounded ridges and spurs, separated by very narrow valleys.	**Mbooni:-** Include a number of isolated high hill masses with steep deeply dissected margins. The summit levels are at 1700 m-2100 m.

The rocks are mainly granitic gneisses of Precambrian metamorphics.	Steep margins are largely bare agroforestation with wattle and eucalyptus and occasional acacia seyal is present.
The rocks include granitic and micaceous gneisses of Precambrian metamorphics with augen gneiss forming unit 8'. Largely exposed. Where concealed the soils are red friable clays and reddish yellow sandy clay loams and shallow stony soil. A quartz gravel is present.	The area is largely cultivated where the soil permits. Forests of wattle and eucalyptus trees are cultivated.

9	This is the low areas among the high hill masses identified on the image from striations representing a strike on the Precambrian gneisses and defined by the major river valleys. On the black and white image especially the MOMS-01 image the zone appears as a grey striated area. On the FCC the area is in the dark green to yellow and appear striated.	**Maiyani:-** Extensive area of ridges and valleys. The ridges have broad rounded crests occasionally elongated. Hills are present The crests occasionally carry black clay soils.	The area is characterized by a variety of gneisses and schists mainly intercalations of graphitic schists, hornblendite, hornblende-biotite gneisses and marble with quartz veins.	The vegetation is mainly scrub or cultivated.
10	These are the hill crests rising abruptly 200-600 m above the flat plains (mainly the lava plains). They have more or less rounded hill ridge crests with rounded spurs extending down from them. The rounded spurs are more conspicuous on the Ngong and Ilemelepo Hills.	**Ngong:-** Several high hill masses that rise from the lava plains south of Nairobi. They differ in detail but they each stand 200-600m above the plain.	The Ngong hills are of phonolite of Tertiary age. Mua Hills and Lukenya are granitoid gneisses. Ilemelepo Hills are limestones and quartzites. The soils vary from hill to hill being dark red friable clay on Ngong Hills and yellow red sandy clay loams and shallow stony soils with rock outcrops on the other hills.	Vegetation ranges from clumped trees in grassland to wet grassland in depressions, forests remnants on steep slopes and scrub or thicket at the valley bottoms.

11 11'	The unit is defined by the low plains in the north east between the Kanzalu range and the Yatta Plateau. It is characterized by bright and dark striations evident on the images. The striations represent low ridges (bright) and troughs (dark) that are cut perpendicular by streams flowing eastwards. The bright striation represent near bare ground.	**Wamunyu:-** Marked by long ridges separated by narrow flat bottomed river valleys and occasional rivers.	The rock units are a variety of Precambrian metamorphic gneisses with some schists.	The vegetation is grass-land mainly acacia savanna.
12	This forms the flat topped plateau to the north east of the area. The south west facing scarp is very much pronounced being enhanced by the shadow effect. On the FCC the unit shows a stippled texture of brown/yellow and green. The scarp is dissected by short river valleys and completely washed away in certain localities. Bright striations are evident on some parts of the plateau.	Yatta:- Marked by a narrow plateau with gentle depressions. Strongly dissected along its margins. The lava is 3-5 km wide and extended south east north west for nearly 200 km.	The rocks of the plateau are Tertiary vol-canics, a phonolite capping over the Precamb-rian metamor-phics. The rocks are concealed by strongly brown clays with laterite horizon.	The vegetation is thicket or scrub on defined margins or grassland with low acacia trees on the flat top.

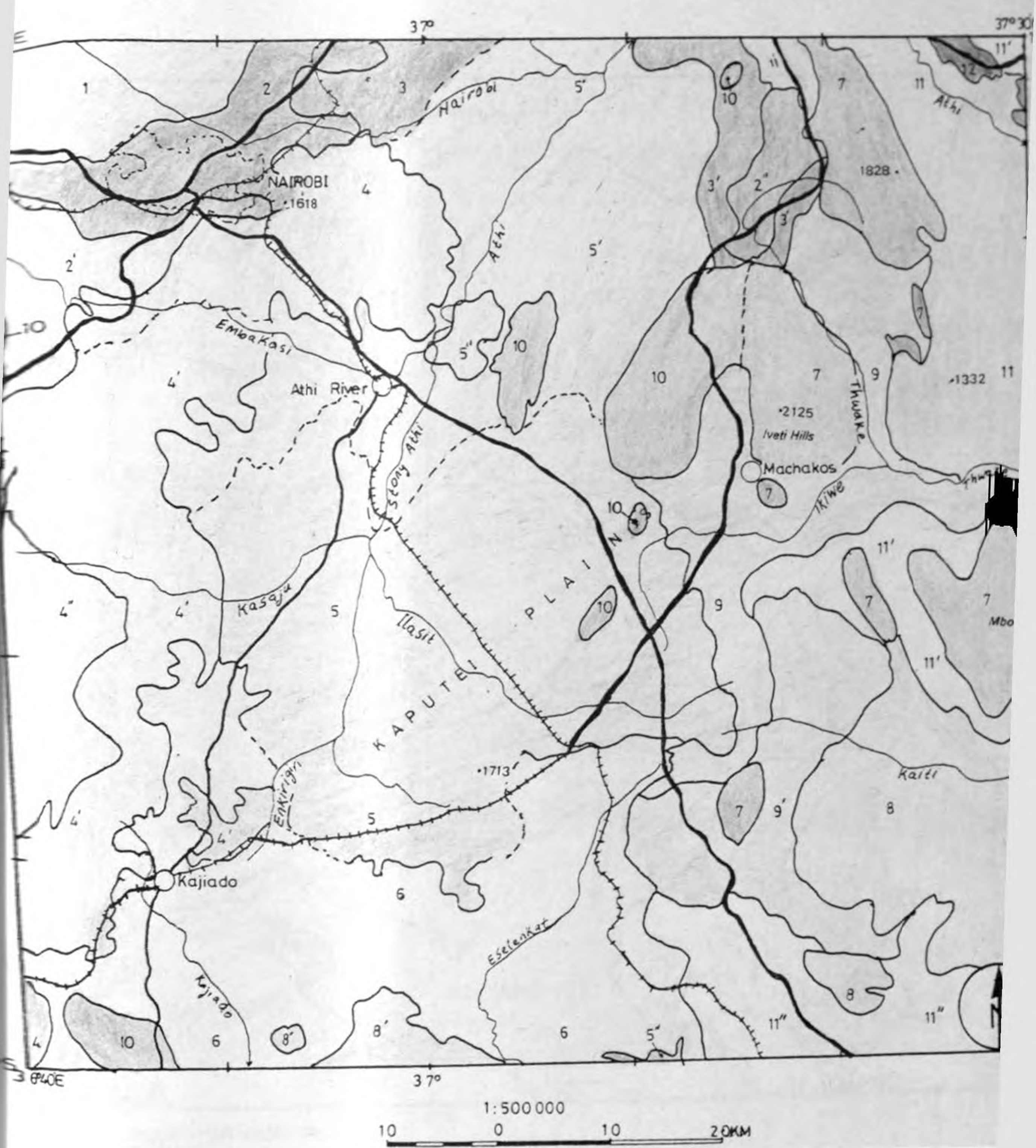


Figure 7 - A simplified map of the study area showing twelve basic land systems identified from Landsat-3-MSS black and white image acquired on 11 Feb.1976 (see plate 1) and Landsat-3-MSS standard false colour composite (FCC) Acquired on 17 Feb 1980. The numerals (1,2,3....) indicate the various land systems and their sub-division (1',2',3"....) These have been compared to the land systems of Scott et al (1971) (see figure 8 and table 4)

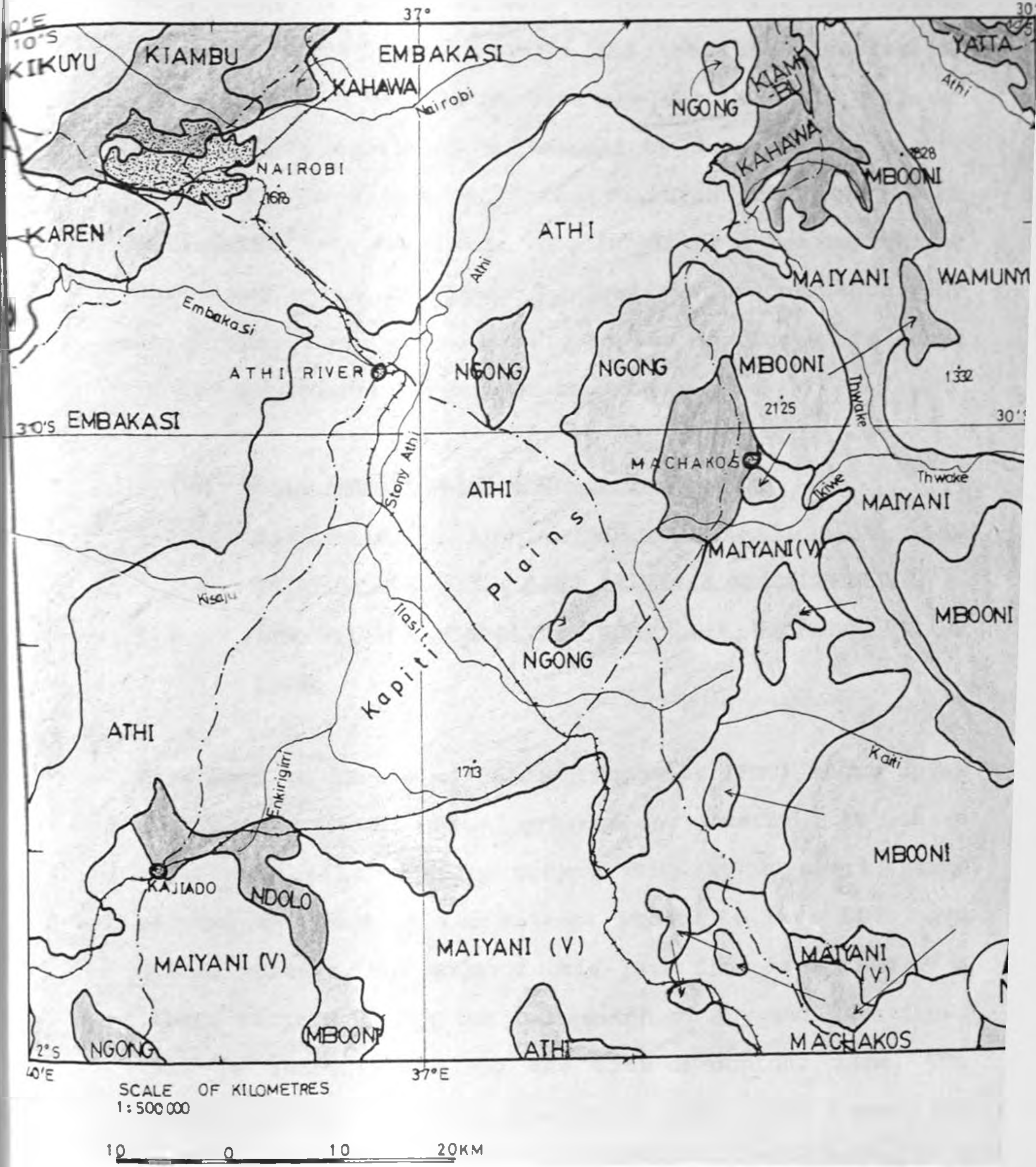


Figure 8 - Map extract from "A Land System Atlas of Western Kenya" (After Scott et al, 1971) showing thirteen land systems. The land systems are explained in table 4.

at a scale of 1:500,000 were compared to the land system units of Scott et al. (1971) and the mapped geological units of the area. The results are tabulated in **Table 4**. The features mentioned and mapped by Scott et al. (1971) are shown in **Figure 8**. These features could easily be delineated from the image. The interpreted remote sensing units are shown in Figure 7. They were supplementary by other auxiliary sources such as the mapping units shown in the geological reports of the area.

4.3 Data Interpretation Specific Areas

4.3.1 Geological Image Interpretation of the Nairobi-Athi River Area (Plate 2 and figure 9).

4.3.1.1 The Nairobi Phonolites and Upper Kerichwa Valley Tuffs

This area on the false colour composite (FCC) shows up as a great area of blue grey/green country. It is a relatively flat country broken only by a short scarp marking the edge of the Nairobi Phonolite lava flow, and stream valleys. The edge of this lava flow is marked by a lobate pattern giving the impression of a young lava flow. This is recognized along the 1560 m contour line. The lobate pattern has been preserved over time suggesting resistance of the rock unit to weathering. This pattern is further enhanced by the development of stream valleys in the areas where the lobes have been incised. The streams have developed into a radial pattern (**Figure 10.2**) indicating a slight subconical isolated elevation towards the city centre. It would appear that the source of this

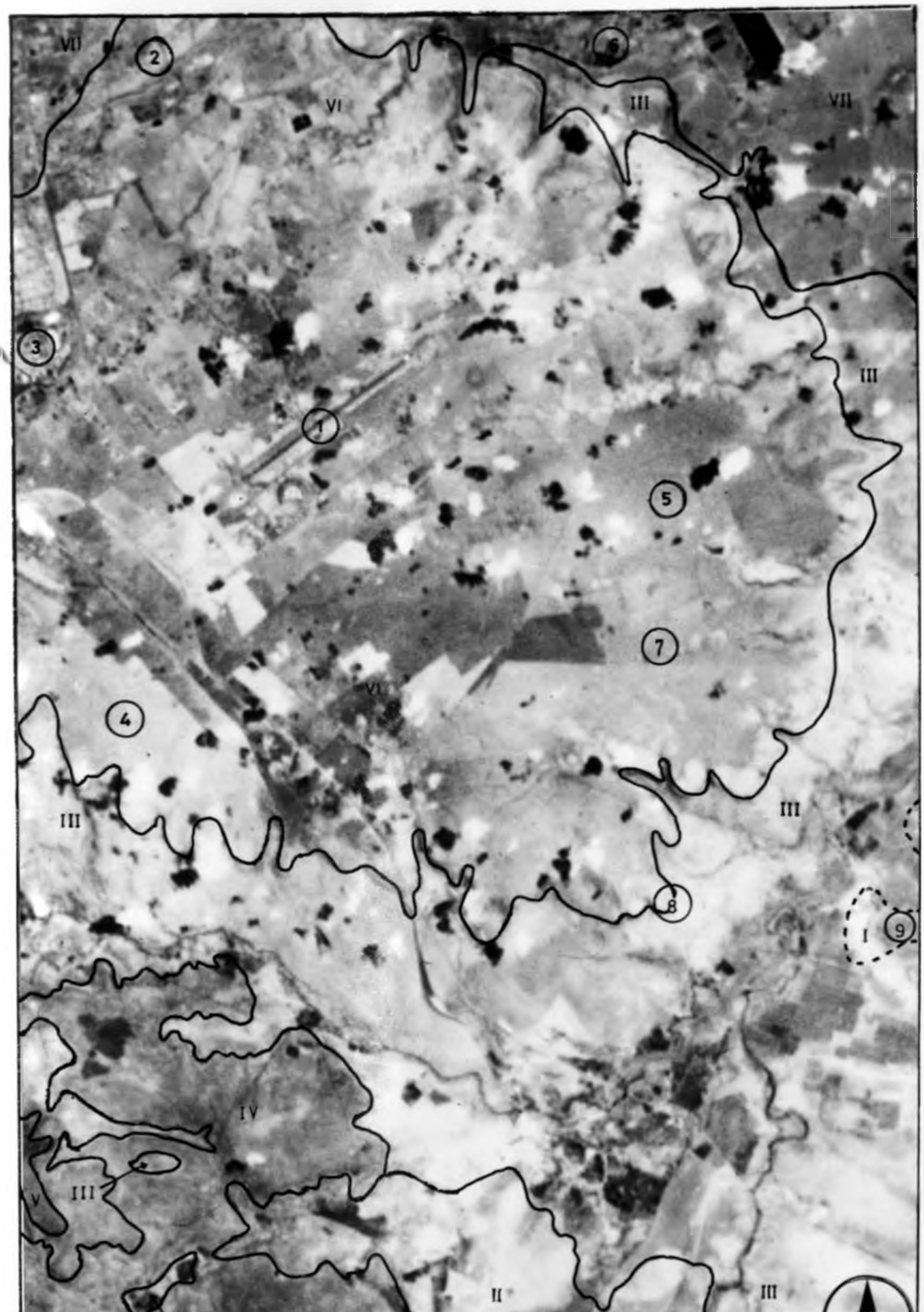


Plate 2—

The Nairobi Phonolite lava sheet 7 forms a distinct edge 8. The dark blue linear feature 1 is the Jomo Kenyatta Airport Runway. The crowded slum of Kariobangi Korogocho 2 shows up as a uniform bright blue. Note the less crowded Industrial Area 3. The contrast in reflectance between the overgrazed Nairobi National Park 4 and the area to the north is prominent. The coffee plantations 6 are in the bright red, the sisal plantations 5 in dark red/brown and the natural dense vegetation 9 in brown.

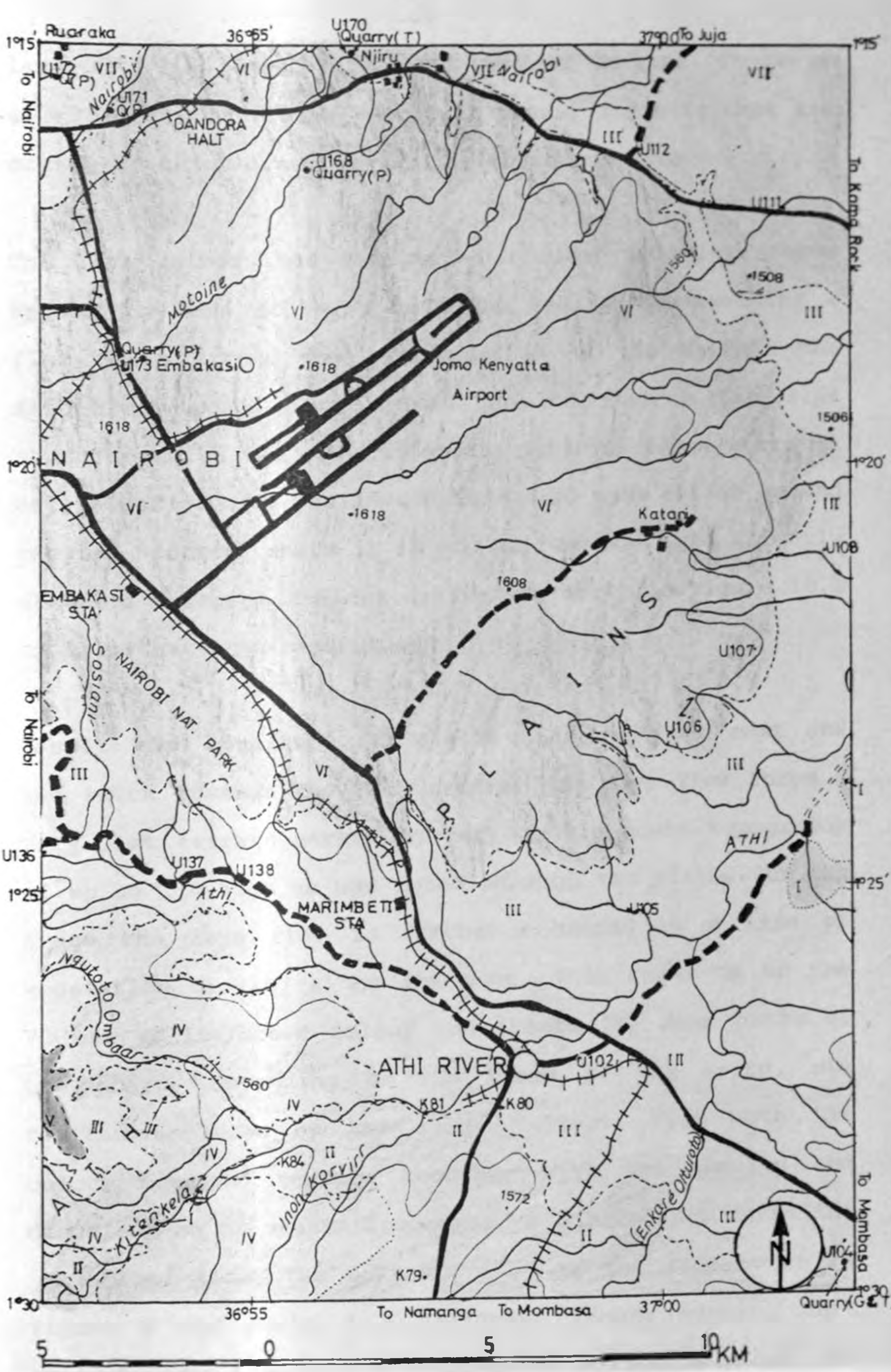


Figure 9 - The Nairobi Phonolite (VI) forms the relatively flat Embakasi/Athi plains. Its edge approximate the 1560m contour. Here the lava forms a scarp against the Athi tuffs (III) which are underlain by the Kapiti Phonolite (II) that in places has been eroded exposing the Precambrian metamorphic rocks (I). A small exposure of Mbagathi trachytes (V) forms a capping on the Athi tuffs (III) which in this part of the area are overstepped by the Upper Athi tuffs and welded tuffs (IV). The Upper Kerichwa Valley tuffs (VIII) overstep the Nairobi Phonolite to the north.

lava flow is somewhere to the west of Nairobi. Scott et al. (1971); Saggerson (Report in press) indicate that the centre of this lava flow was the Aberdare volcano.

The lava rather than flowing as a sheet from its source appear to have followed a stream valley. On reaching a flat plain around the present site of the Nairobi the slightly viscous lava spread out to form a fan like structure with the edge extending to form lobes where it met raised ground. The lava piled up to some extent around the new "source" where it is now represented by a slightly elevated terrain. A block diagram is shown in **Figure 10.1** to illustrate the assumption.

Despite the apparent very gentle rise from the east and the south towards the city centre, the lava flow forms a very flat terrain marked by very gentle mound topography of up to 1 m high as was noted through the plains. On the image the lava flow is further enhanced by a line of vegetation growing along its edge. This shows up on the FCC as yellow/brown colour hue (**Plate 2**). Some parts of the scarp, depending on the trend of the scarp, are further enhanced by the shadow effect. From both the colour hue and texture together with the density and distribution of vegetation cover, a single unit forms the phonolite. Along the northern edge of the area shown in **Figure 9** and Plate 2 a different remote sensing unit conceals the topographic expression of the edge of the Nairobi Phonolite.

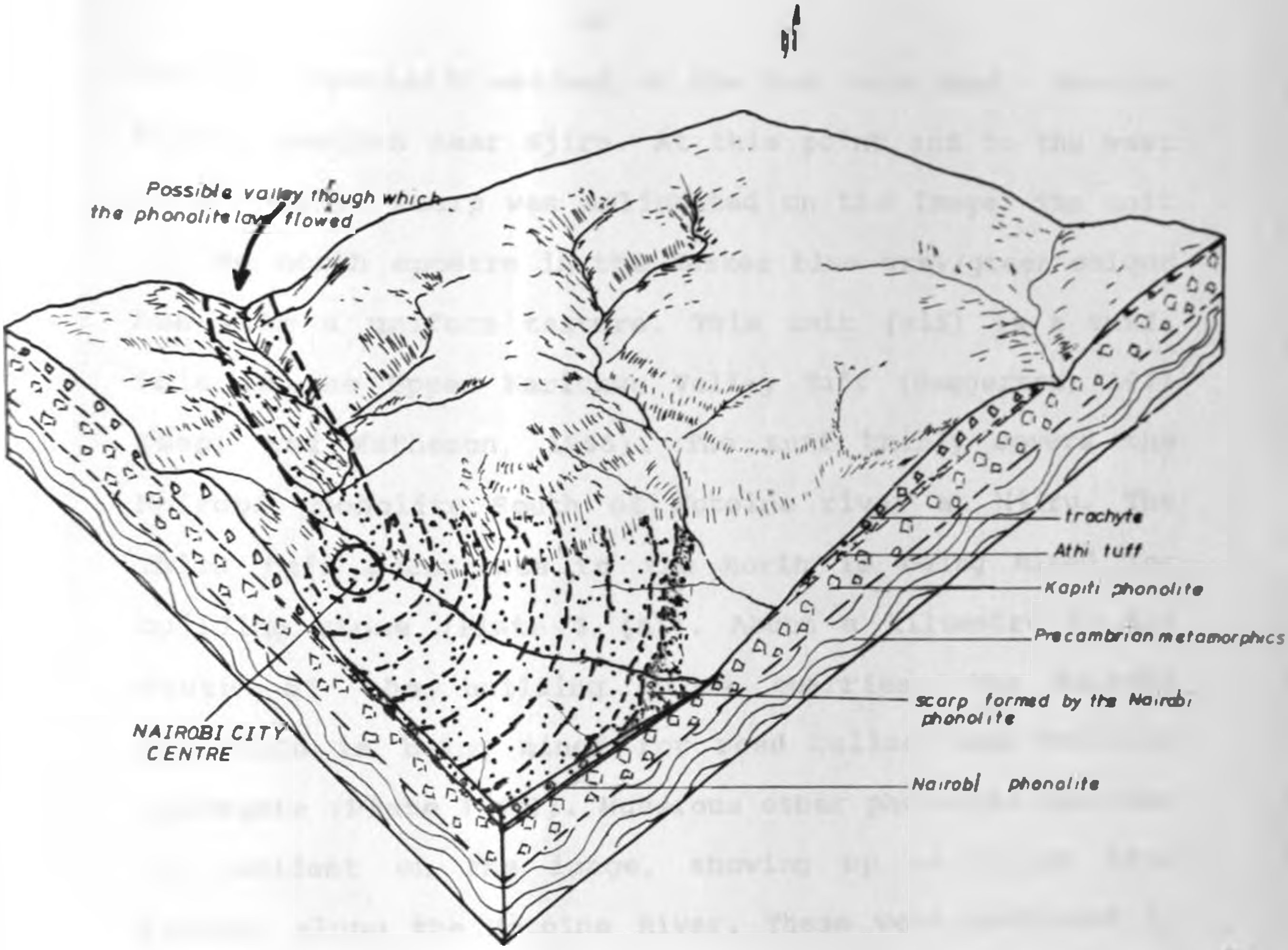


Figure 10·1- A block diagram showing the possible extent of the lavas at the end of the Nairobi Phonolite lava flow. A possible valley through which the phonolite flowed is shown.

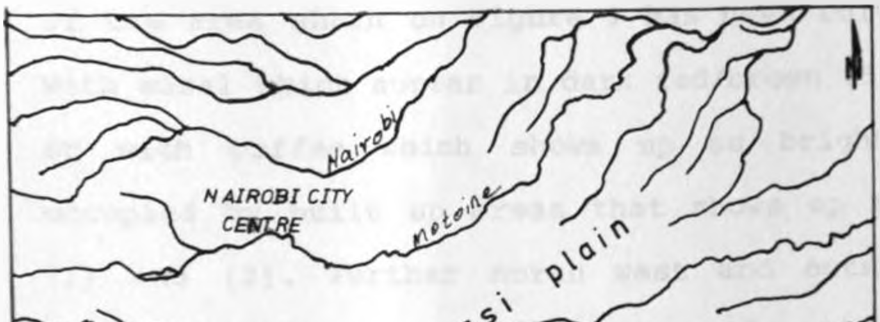


Figure 10·2- A near radial drainage pattern observed on the Nairobi Phonolite.

This is especially evident at the Koma Rock Road - Motoine River junction near Njiru. At this point and to the west no phonolite scarp was delineated on the image. The unit to the north appears in the darker blue grey/green colour hue with a uniform texture. This unit (vii) is a tuff. This is the Upper Kerichwa Valley Tuff (Saggerson, 1971 (map) and Matheson, 1966). The tuff thinly covers the Nairobi phonolite South of Motoine river at Njiru. The thick tuff occurrence to the north is being mined for building stone (Plate 3 **(a)**). About a kilometre to the south of the building stone quarries, the Nairobi phonolite is being mined for road ballast and building aggregate (Plate 3 (b)). Numerous other phonolite quarries are evident on the image, showing up as bright blue patches along the Motoine River. These were confirmed in the field.

A large part of the area covered by the tuffs to the north of the area shown on **Figure 9** has been cultivated either with sisal which appear in dark red/brown (5)* in the FCC, or with coffee which shows up as bright red (6) or occupied by built up areas that shows up as bright blue (2) and (3). Further north west and outside the frame shown in Plate 2, a large human settlement has interfered with the natural set-up of the land. The presence of diverse cultural features especially the built up areas and the cultivated areas blend with the natural features giving a spectral signature that is non-specific for the area. The geomorphology as expressed on the image then

* *the numbers (5), (6), etc are explained on the plates .*

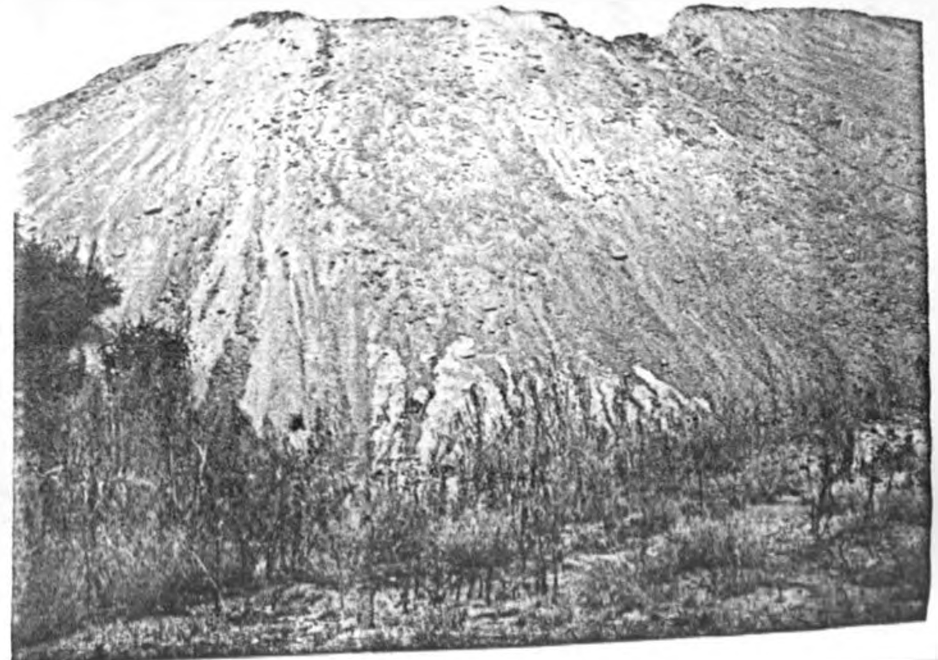
(A)

(B)

Plate 3: Mining activities (a) A tuff quarry for the Nairobi blue stone at U169 at Ruiruaka river valley near Njiru. (b) A phonolite quarry at U166 near Njiru. (c) A marble quarry at U63 near Kaani. Note the poor mining method. (d) A pile of waste from Kunkar limestone extraction for cement processing, 10km west of Athi River.

(C)

(D)



affords an invaluable tool in determining remote sensing units here. However the tuffs form no prominent topographic expressions, and it was difficult to determine the edge of the pyroclastics from the image.

4.3.1.2 Nairobi Trachytes

The scarp noted forming against the Nairobi Phonolite to the western parts of the area is that of another the Nairobi Trachytes lava flow. Relative to the phonolite it is a younger lava flow. Its scarp is an expression of the edge of the lava flow and thus the limit of its lithologic boundary. This topographic expression of the edge was traced on the image just to the west of Nairobi City Centre along the 1620 m contour line. It runs from the Museum area through the University sports ground to beyond the Nairobi Dam. Field evidence showed that the Nairobi-Nakuru railway line closely follows the foot of the scarp from the Uhuru Highway crossing to Kibera Station. In certain localities such as the Railway Golf Course the trachyte lies directly on the phonolite while in other localities it overlies Lower Kerichwa Valley Tuff in the area further west of the area shown in Plate 2.

4.3 1.3 Athi Tuffs and Lake Beds, Kapiti Phonolite and Precambrian Metamorphic rocks.

Underlying the Nairobi Phonolite and exposed to the east and south are the Athi Tuffs and Lake Beds (III). The region occupied by these tuffs appears in the lighter blue/green colours due to the blended reflectance of the light coloured soils and the savanna grassland, different from the blended reflectance of the black cotton soil and the savanna grassland. This unit extends east onto gneisses of the Precambrian metamorphic rocks where at the edge it shows a marked change in reflectance from light blue/green to yellow/white or yellow/brown. The tuffs are noted overlying the Kapiti Phonolite which is exposed mainly in the Kitenkela river and the Mambariswan rivers and to the south east of the present area. The Kapiti Phonolite overlay the Precambrian metamorphic rocks of locality u102 just South east of Lukenya Hill. Around the Athi River area, the dark patches and red/brown areas, also located further north along Athi river, are cultivated fields. Field survey indicates a sandy light grey to grey clay loam found along this part. The sand is probably due to erosion deposit from the Lukenya Hills which are composed mainly of granitoid gneisses of the Precambrian metamorphic rocks. These hills are located just to the east of the area.

4.3.1.4 Mbagathi trachytes and Upper Athi Tuffs and Welded Tuffs

In the south west end, the reflectance characteristic of the remote sensing unit (IV) is in the dark grey/green with an irregular near stippled texture. These form the Upper Athi Tuffs and welded tuffs overlying the Athi Tuffs and Lake Beds and Kapiti Phonolite that are exposed along the deep river valley of Kitenkela. Here, where there has been deeper erosion, the Precambrian metamorphic rocks are also exposed. The unit (V) is the Mbagathi Trachyte, which directly rests on the Athi tuffs and welded tuffs in the area further west. Saggerson (Report in press) indicates that the Mbagathi trachyte is older than the Nairobi Phonolite. It follows then that since the Mbagathi Trachyte rests directly on the Upper Athi Tuffs and welded tuffs, this unit (the Upper Athi Tuff) is older than the Nairobi Phonolite.

4.3.1.5 Cultural Features

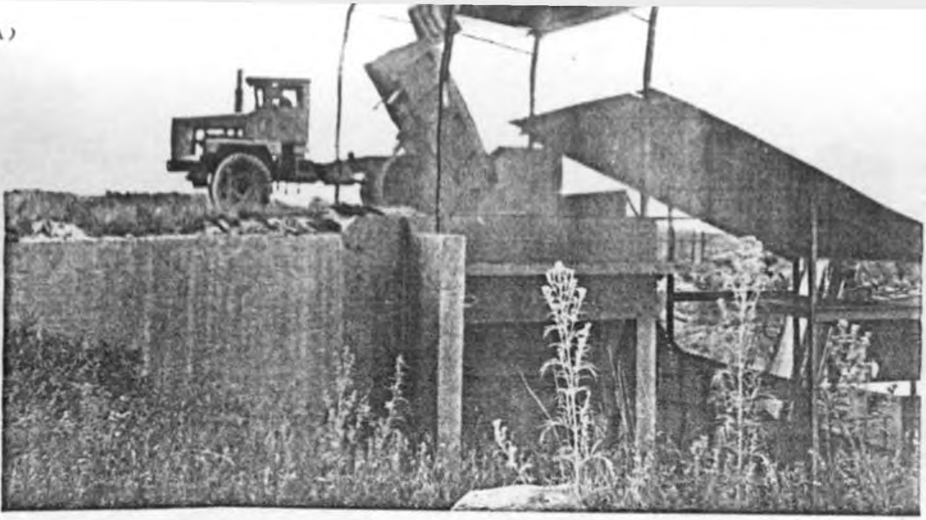
Within the area shown in Plate 2 several spectral signatures are eminent. There is a marked difference in the spectral signature of the reflectance of the surface inside the Nairobi National Park (4) and that outside the park. The area outside the park is characterized by a darker blue grey/green colour while the park shows up in a lighter blue/grey, yellow/green colours. This spectral difference enhances the northern perimeter fence of the park. The southern boundary is marked by the Embakasi and Athi rivers.

Field investigation revealed an overgrazed land inside the park where the movement of the wildlife is limited by the perimeter fence. Outside the park the savanna grasslands thrive naturally affected little by the Maasai cattle.

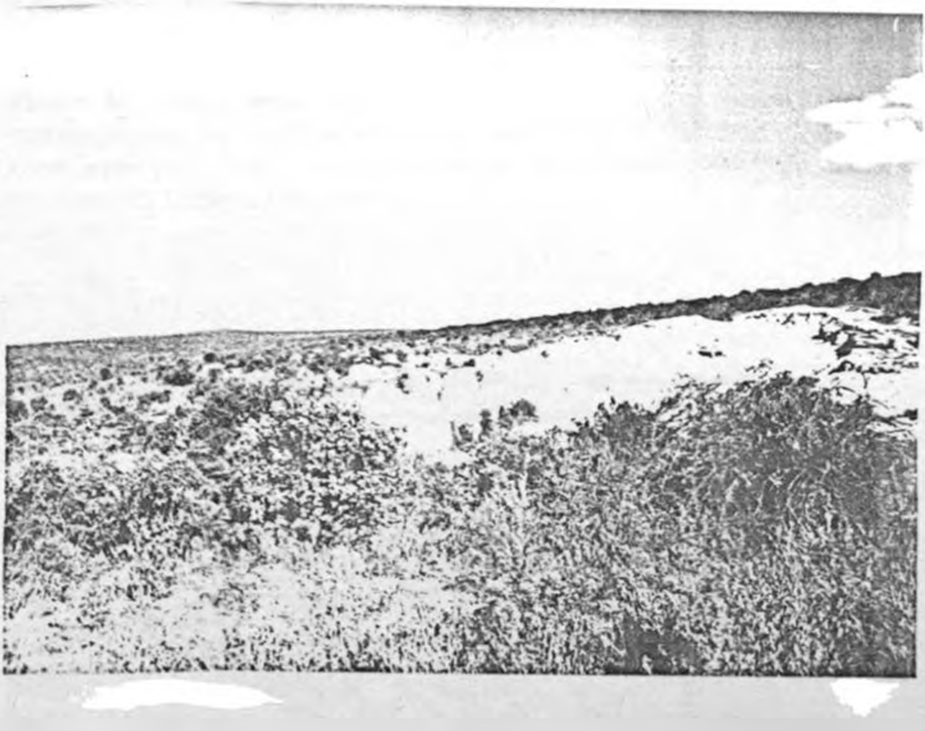
The bright blue linear features evident on the image are tarmacked roads observed because of the high reflection from their surface. The Mombasa road runs centrally in a north west-south east direction. Of conspicuous occurrence is the Jomo Kenyatta International Airport (1) Runways. Note the semi- circular feature that represent the Terminal Building. The blue patches seen along the Motoine River are quarry pits (Plate 3 (b)) and the phonolite rock crashing sheds (Plate 4 (a)). Along the Nairobi river similar patches are seen in older images but these are now replaced by a larger occurrence of shanty towns such as the Kariobangi, Korogocho slum areas (2) **(Plate 5 (e) and Plate 6)** lying next to abandoned quarries. This area shows up on the image as a uniform bright blue indicative of crowded housing lacking sufficient infrastructures and recreation facilities. The town centre **(Plate 5(a) and (b))** and the industrial area (3) appear in stippled blue patches sometimes with well planned roads going through. Just to the north of the portion of industrial area appearing in Plate 2, is the Buru Buru Estate characterized by yellow/blue colours due to the reflectance from the brick roof tops. Note the well planned roads and the contrast in reflectance from this estate and that of the adjacent Umoja Estate with its corrugated iron roof tops. The contrast in reflectance of the two estates enhances the reflectance of the Outer-Ring Road which passes between them.

The infrastructures are built on the Nairobi phonolite which is a structurally stable rock providing a firm foundation and stable base. The thin soil cover over this rock provide easy excavation for foundations. The phonolite itself is an invaluable stone for building aggregate and road ballast.

(A)



(C)



(B)

Plate 4: Mechanized rock processing plants. (a) A lorry tipper pouring rock into a crusher at a phonolite quarry near Embakasi. (b) An abandoned marble quarry at U63 near Kaani. (c) A pile of waste from the rock crusher at the Kenya Marble Quarry south west of Kajiado. (d) Crushed rock conveyer belts at the Kenya Portland Cement field plant, 10km east of Athi River.

(D)

(A)

(B)

Plate 5: Urban developments in the area. (a) Nairobi city centre's skyscrapers with the surrounding terraced Uhuru Park The terrace is on the edge of the Nairobi trachyte lava flow. (b) Road infra-structures and parks, south west of the town centre. (c) A panorama of Kariobangi Korogocho slum. Compare with the city centre! At the foreground is an abandoned phonolite quarry.

(C)

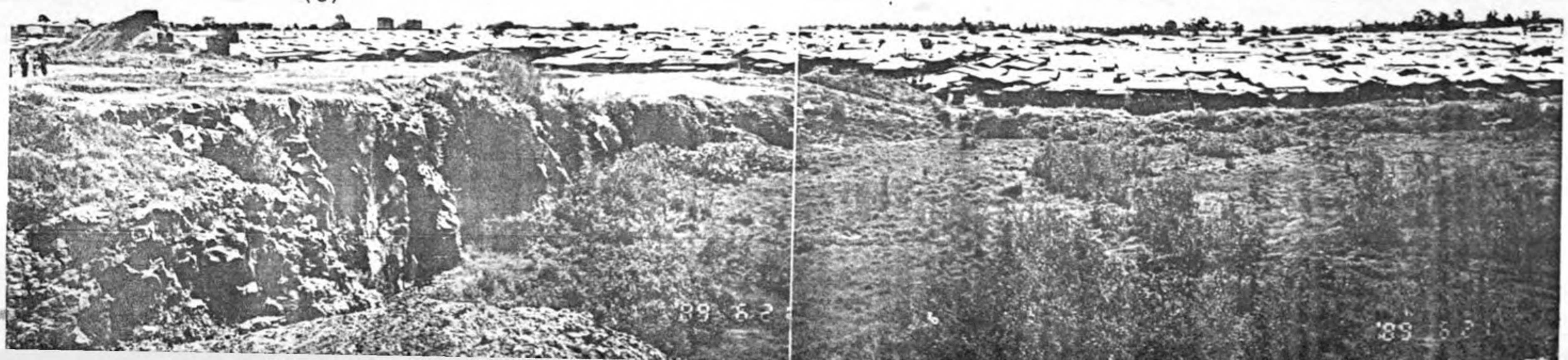


PLATE 6: A Panoramic view of Kariobangi Korogocho shantytown. The circular feature on the left background (arrowed) is the ultra-modern Moi International Sports Complex.

4.3.2 Geological Image Interpretation of the Olooloitikoshi Area (Plate 7 and figure 11)

The Olooloitikoshi area shown in Plate 7 and figure 11 was registered in a false colour composite (FCC) with the green colour filtered out. The north west corner is the lower slopes of Ngong Hills. The area is exploited for agriculture. At the time of the year when the TM image was taken, 27 November 1985, the cultivated fields were largely fallow. These were ploughed and bare. On the image the ploughed fields (1) show up as black patches because they reflect little of the sun's energy. The fields are small scale holdings and the scattered plots give the image a stippled appearance.

4.3.2.1 Structural Geology

This area is further defined by a dendritic drainage pattern that is enhanced by a high chlorophyll riverine vegetation (2). This vegetation shows up as a line of bright red defining the rivers on the image. Many faults appear as linear features trending in a north south direction. They are recognized as streaks of dark lines. The faults are down-thrown to the west and the west facing scarps are enhanced by the shadow effect.

The faults are best recorded in the remote sensing unit (X). To the south they are concealed by the unit (VII') although a few linears are noted extending to and affecting this unit. It would appear that the unit (VII')

Plate 7 —
The area is just at the edge of the Eastern scarp of the Rift Valley. Numerous lineaments (faults) indicated thus ( ) can be picked from the image. The dark zone (1) in the area are ploughed ground. The north western corner is the lower slopes of Ngong Hills. Note how the stream valleys (2) are defined by vegetation. A scarp (3) can be picked from the image.

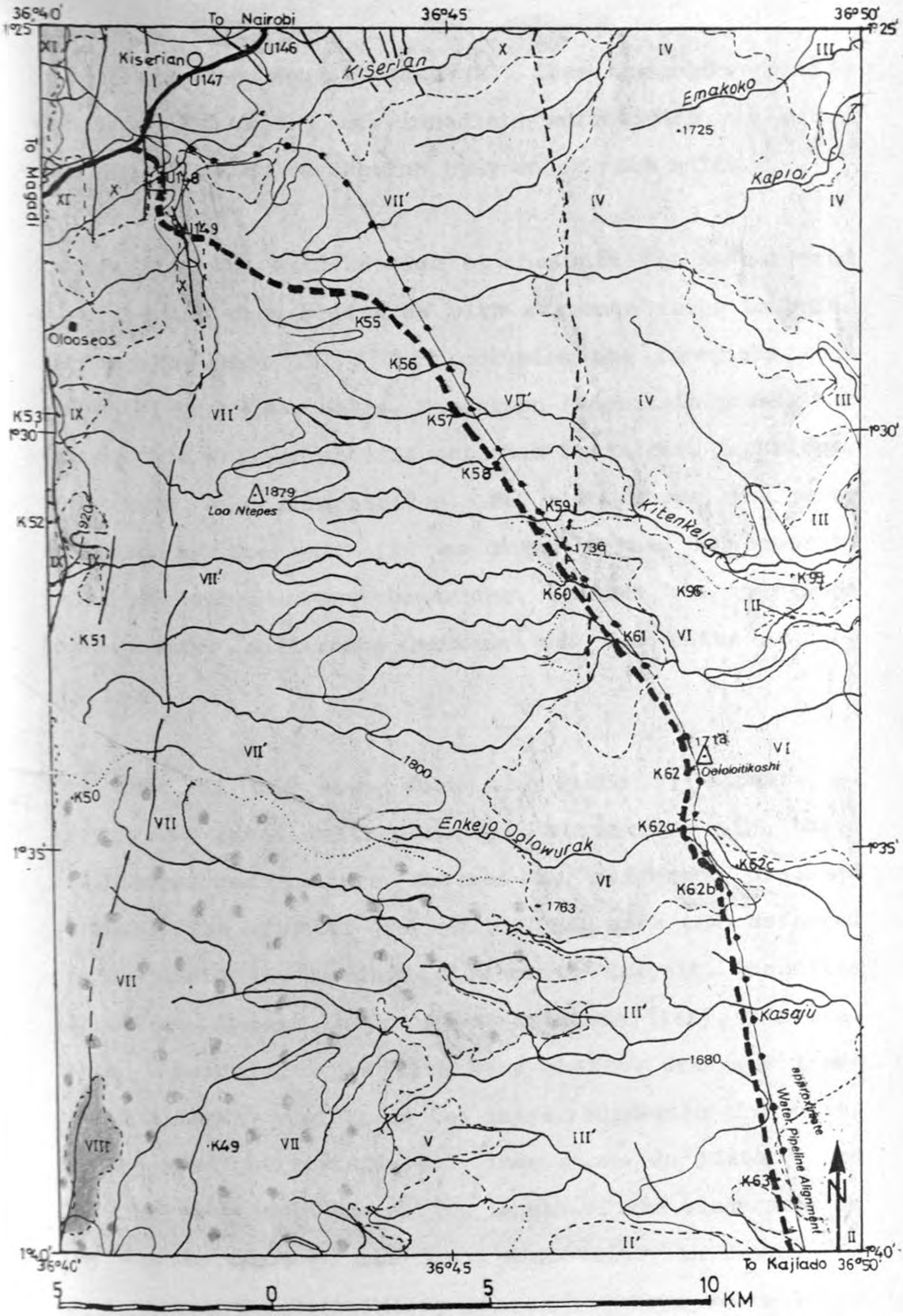


Figure 11 - The rocky Ol Doinyo Narok agglomerate (VII) forms a scarp to the east and show a pinnate short drainage pattern that grade into a parallel drainage pattern where a tufficeous agglomerate (VII') was identified. The Olorgesailie phonolitic nephelinite (VI) forms a distinct scarp against the Athi and Upper Athi tuffs (III, III'). The oldest lava flow is the Kapiti phonolite (II) noted eroded and weathered into black cotton soil underlain by Precambrian metamorphic rocks (IÍ). Other units noted are Mbagathi Trachytes (IV), Olorgesailie Biotite phonolite (V), Phonolite in Ol Doinyo Narok agglomerate (VIII), Ol Esayeiti Phonolite (IX) and tephrites and basanites (X, XI).

is a later lava deposit than (X). Thus the rocks forming the Ngong Hills and its immediate surrounding are older and are concealed further on by younger rock units.

On the FCC, the western edge of the unit (X) is bordered by a reddish grey/blue area with a smooth image texture, forming the unit (XI). This occupies the immediate foot slopes of the Ngong Hills. Saggerson (Report in press) has mapped this unit as undifferentiated basanites, tephrites, atlantites and ankaratrites. He also shows the area occupied by the unit (X) as being formed by separate units of tephrites and basanites. However, on the image the spectral difference between the two units is not distinct.

The rest of the area shown in **Plate 7**, appears as grey/blue areas with several variations in their brightness and texture defined by different drainage patterns. The brighter grey yellow/blue area (IX) as noted in the field is the lava flow of Ol Esayeiti Phonolite (Saggerson, Report in press and Matheson 1966). The area shows a smooth texture with very shallow drainage lines that are hardly visible on the image. Bordering this unit, to the west and outside the area shown in **Plate 7** and running north south the entire length of the study area is the eastern scarp of the Great Rift Valley in Kenya. The land within the Rift Valley has sank 600 to 900 m below the surrounding plateau. As is indicated by the drainage lines the plateau is slightly tilted to east with the streams flowing east on this back-slope. The last faulting in the Rift affected all the units close to the scarp. The image displays these faults as numerous north south series of dark lines and streaks all through the portion of scene outside the present study area. A portion of one of the scarps (4) is visible on the image.

4.3.2.2 Ol Doinyo Narok Agglomeratic Tuffs

A portion of the back slope of the plateau evident on the image is that occupied by the unit (VII'). This unit has a characteristic drainage pattern. The pattern is an equally spaced parallel drainage flowing in an easterly direction. The pattern gives an image of striated texture. This pattern points to a homogenous rock with a regional slope, probably due to the tilting of the plateau. The drainage lines are enhanced by the presence of a riverine vegetation that appear as lines of light brown to yellow/red on the image. The streams are sinuous and have wide valleys that appear as a bright grey area on either side of the riverine vegetation line.

The meanders marking the stream are readily traceable from the vegetation. The number of changes in direction of the meanders is regular across the unit (VII'). This regular meander frequency correlate to the underlying rock and were used to map the unit from the image. The direction of flow of the streams (east direction) is perpendicular to the sun azimuth at the time of the day the satellite collected the data. This contributed to the enhancement of the streams. To the east the parallel streams join up to flow in relatively few rivers with differing meander frequency and direction of flow. The confluence of the parallel streams was also used to map the edge of the unit (VII'). Field evidence indicated the unit (VII') to be composed of a light white/yellow agglomeratic tuff, that is a relatively soft rock. These are the Ol Doinyo Narok agglomeratic tuffs (Matheson, 1966).

4.3.2.3 Ol Doinyo Narok Agglomerates

To the south the parallel drainage pattern breaks into an irregular drainage pattern generally flowing eastwards. Both the major rivers and the smaller tributaries have cut deep into the rock exposing very high scarps. The area is also characterized by short pinnate drainage patterns (figure 12). This pattern is indicative of the presence of a resistant rock. Unlike many streams in the area, the Kasaju river at this point shows a concentration of

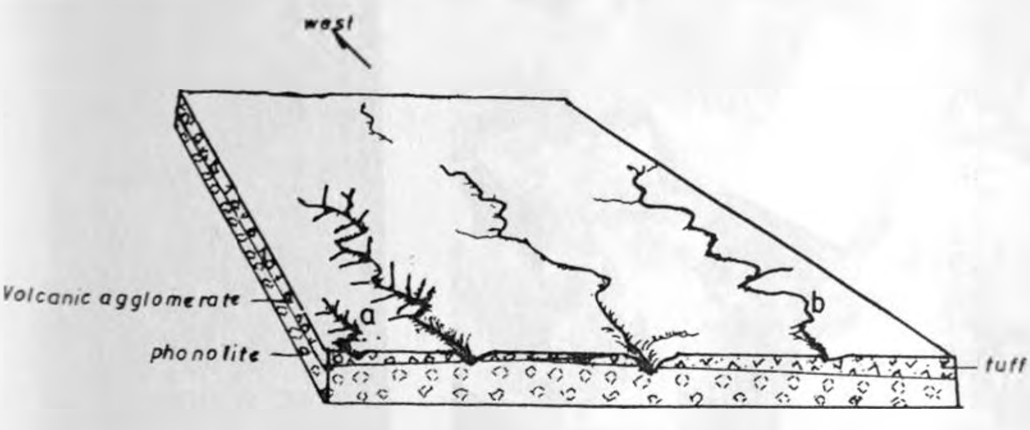


Figure 12- A pinnate drainage pattern(a) on the agglomerate. Note the marked absence of this pattern on the tuff to the north(b)

(A)

(C)

(B)

Plate 8: Extensive outcrops of volcanic rocks. (a) Agglomerate outcrops on Embetera Hills. (b) Soft yellow/white agglomeratic tuff a gradation from the agglomerates, at U143 at Kipeo river.
(c) Soft tuff in (b) Underlain by a grey welded trachytic tuff. Used as a tough building stone.
(d) A highly jointed tuff at a quarry (K90), at Olooloitikoshi river.

(D)

vegetation. It appears as a line of bright red on the image which indicates an increased moisture concentration relative to the surrounding area. Such a place is a probable area for water tapping, given that the ground condition of the area is dry much of the year.

The unit (VII) located in this area corresponds to agglomerates (Matheson, 1966). This rock is a tough highly welded grey to brown agglomerate. These are represented by very extensive rock outcrops (**Plate 8 (a)**). On the image, there is no distinct boundary between the agglomerates and the agglomeratic tuffs. The two rocks grade into one another with the agglomerate softening out gradually towards the north culminating in a very soft tuff. The agglomerate appears to form a scarp against the rock units (III) to the east and south. Within this unit (III') conspicuous streams are absent. A few streams that start on the agglomerate disappear into this unit indicating that the unit (III') is a softer and more porous rock.

4.3.2.4 Olorgesailie Biotite Phonolite and Kapiti Phonolite

Further south into the area outside Plate 7, the agglomerates form large rock outcrops, culminating in the massive hill of Embetera. Field evidences showed this unit overlaying the Olorgesailie Biotite Phonolite (Matheson, 1966). The phonolite is exposed to the south and forms a scarp against the Kapiti phonolite. Along the base of this scarp the Oloyiangaleni river flows south west structurally being controlled by the scarp. At edge of the rift valley from where its drops into the floor of the valley. It has cut very deep into the rock creating a ravine over 100m deep at locality K42 (**Plate 9** (b) and (c)). The rocks exposed at the cliffs have vertical cooling joints in the deeper situated rocks indicating slow cooling. The rocks above this show horizontal cooling joints and stand out as slabs .1m or more thick. Observations and measurements in the field show the rock unit bearing very large nepheline phynocryst measuring over 4 cm long and generally oriented on average N40^{o}W. This unit (V) is the Olorgesailie Biotite Phonolite which on the image appears to have a characteristic darker blue/grey colour hue with a uniform texture.

4.3.2.5 Olorgesailie Phonolite Nephelites Upper Athi Tuffs and Athi Tuffs and Lake Beds

The scarp marked (3) on the image, continue northward and borders the eastern edge of the lithologic trace of the unit (VI). This scarp is defined by a line of vegetation and the spectral difference between the slope of the scarp and it surrounding. The scarp is further enhanced by the shadow effect depending on its orientation in relation to the sun azimuth. Field evidence (**Plate 11**), as noted at locality K62 at Olooloitikoshi, indicate the scarp as being formed of phonolitic rock boulders occupying the steep to gentle slopes. The scarp holds a vegetation of taller grass with a slightly increased number of scattered trees in relation to the surrounding. The river has eaten

(A)

(B)

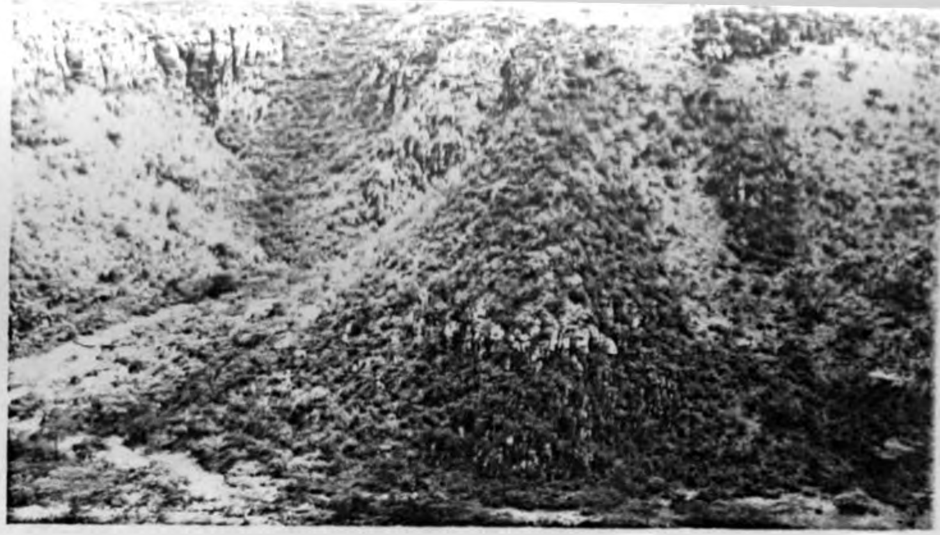


Plate 9: Contrasting relief. (a) The flat Kaputei plain with its savanna grassland (dry at this time of the year) and acacia drepanolobium trees. At the far horizon are the Embetera Hills. (b) and (c) A close up of the Embetera Hills. The streams have eroded into the Olorgesailie Phonolite exposing vertically and horizontally jointed rocks. The denser vegetation show up clearly on the images, enhancing this feature. (d) Coffee plantations around Ol Donyo Sabuk Hill at the background. A red volcanic soil derived from the metadolerites is evident.

(C)

(D)

into the lava flow, causing it to have long near parallel scarps facing one another. This is evident on the image. The phonolite is the Olorgesailie Phonolite nephelinite (Matheson, 1966).

The scarp forms against a grey welded tuff (Upper Athi tuff (III')) that further east is replaced by a light yellow/white soft tuff with a bedded appearance (Athi tuffs and Lake Bed (III)). This light yellow tuff also occupies the river valley of Kitenkela, Emakoko and Kepio along the eastern margin of the area. It was determined and outlined from the image from the light grey to yellow colour hue. In the area further east and outside Plate 7 the welded tuff is being mined for building stone. These are extensive mining (Plate 8 (b) (c) and (d)) places. The lithologic succession of the rock units were easily determined at these quarries with the Kapiti Phonolite occupying the base and overlain by the Athi tuffs and Lake Beds which in turn are overlain by the Upper Athi tuffs and welded tuffs.

4.3.2.6 Mbagathi Trachytes

In the north eastern part of the area shown in Plate 7 another scarp forms against the tuffs to the east. Delineated is the unit IV that shows up in slightly stippled darker grey/blue colour hue and show very shallow drainage lines with hardly any vegetation growth in them. The direction of flow of these streams makes it difficult for the water courses to be identified because of shadow effect. Matheson (1966) and Saggerson (in publication) have mapped this unit as Mbagathi trachytes. They indicate that the unit is older than the tuffs which overlie it to the west and conceal the unit. The Olorgesailie Phonolitic Nephelinite also partly conceals the Mbagathi Trachytes and are also younger.

4.3.3 Geological Image Interpretation of Sajiloni Area (Plate 10 and figure 13)

4.3.3.1 Kapiti Phonolite

The false colour composite (FCC) of the Sajiloni area was overprinted with yellow colour. This enhanced the broad scarp that is 1 to 2.5 Km wide, representing the edge of Kapiti Phonolite lava flow (2). On this composite the edges shows up in a dark brown to red colour hue. Like many of the scarps representing the edge of the other lava flows elsewhere in the study area, it is marked by the presence of large lava boulders on the scarp. Field evidence revealed the presence of Precambrian metamorphic rocks quite high in the scarp. The lava capping to the north has preserved the Precambrian rocks from weathering and erosion. The rock boulders hold pockets of soil which seem to hold more moisture and a thick vegetation growth is evident along the scarp. The top of the scarp is the lithologic trace mark of the unit (IX) which is the Kapiti Phonolite lava flow. The base of the scarp is another lithologic trace mark representing the lower limit of the phonolite rock boulders. The zone marked by the two

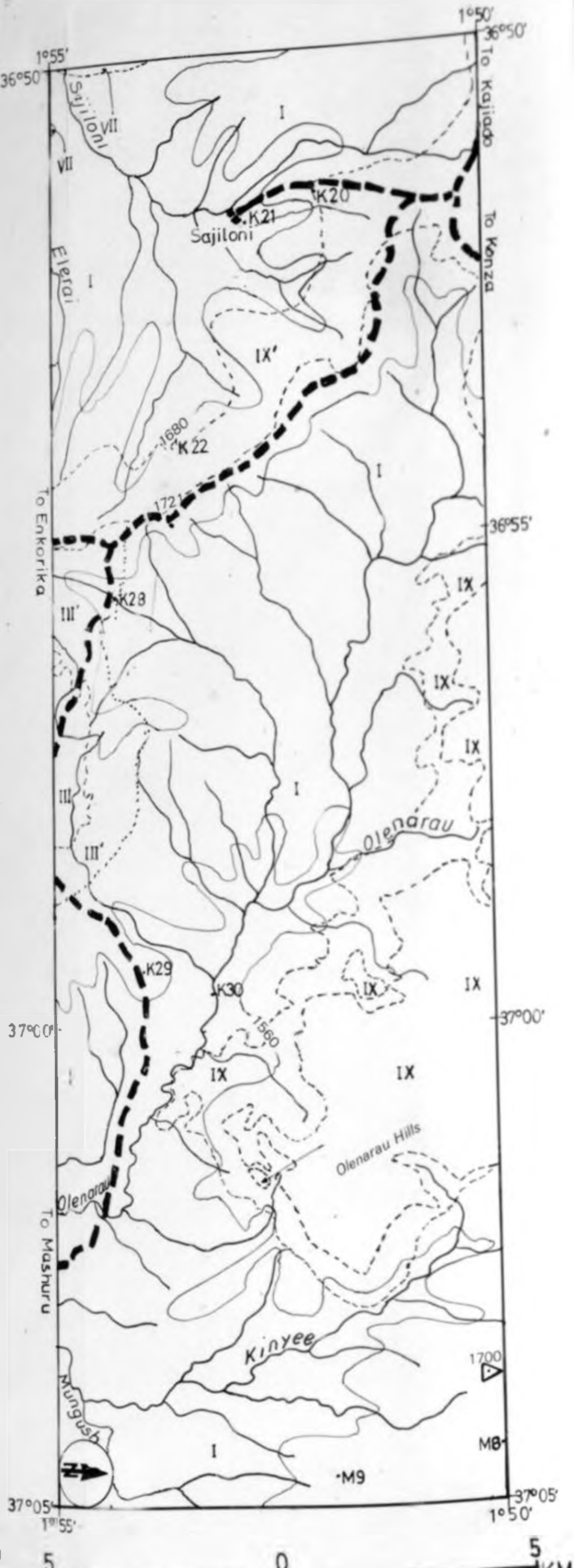


Plate 10 –
The edge of the Kapiti Phonolite lava flow. The lava flow (1) forms a well defined edge (2) against the Precambrian metamorphics (4). At (3) the lava has completely weathered into a black cotton soil. The lithologic units I, III, III', IX, IX' are explained in the figure.

Figure 11 – The crystalline rocks of the Precambrian metamorphics on the standard false colour composite appear in yellow/brown to dark brown in the [illegible] The lavas are [illegible] blue to dark blue colour [illegible]. The remote sensing units interpreted from the image correspond to [illegible] undifferentiated crystalline rocks of the Precambrian metamorphics mainly biotite gneisses, hornblende-biotite gneisses, quartzo-felspathic gneisses and granitoid gneisses (I), granitoid gneisses (III), Augen gneisses (III'), Kapiti Phonolite (IX), Black cotton soil with isolated thin exposures of Kapiti phonolite and phonolite boulders at the scarp (2) and underlain by (1) (IX').

lithologic trace marks is the unconformable surface between the Precambrian metamorphic rocks and the volcanics.

The Kapiti Phonolite lava flow probably flowed on a peneplain slightly tilted to the south east (Matheson 1966). The flow could have met a raised ground which it piled up, leading to the formation of the distinctive scarp evident on the image. In some places the capping lava is thick and has preserved the peneplain under the Olenarau Hills to the north of Olenarau river. The lava was probably more extensive in its initial spread. As pointed out by Walsh (1963), feldspathoidal lavas are the least viscous of any kind of lava. This can easily spread out first following the valleys. A tongue of it probably flowed further south just to the west of the present Kajiado- Enkorika road.

It would appear that this tongue of lava initially cooled to form a ridge like feature that at present forms a watershed for two drainage basins. The Sajiloni river and its tributaries form drainage basin to the west and the Olenarau river and its tributaries another drainage basin to the east. The main edge of the lava flow also forms a major watershed between the drainage basin to the north and another to the south. The drainage basin to the north is largely confined to the lava plain, except where the lava has been completely eroded or the Precambrian metamorphic rocks were not completely covered. The drainage basin to the south is confined entirely to the

Precambrian metamorphic terrain. In the flat lava plain the drainage pattern to the north has dissected little into the rock and appear as very shallow drainage lines. As a result there are generally very poor exposures. Where the rock is exposed in some streams and some parts of the plain the outcrop are rounded exfoliated boulders as noted in the field. The thickness of the phonolite is very variable as is also noted by Matheson (1966). The lava flowed on an irregular sub-Miocene surface and was extruded around hills rising above the peneplain. These hills were noted in the field dotting much of the area just to the north of the area shown in Plate 10.

4.3.3.2 Black cotton soil with exposures of Precambrian metamorphic gneisses and thin exposures of Kapiti Phonolite

The tongue of lava that probably flowed southward and formerly occupied the area to the west of Kajiado-Enkorika road is no longer preserved. It has completely been weathered out into a black cotton soil. This soil is the only remnant evidence of the Kapiti Phonolite. The area delineated as the unit (IX') from the image (Plate 10) appears as a dark grey/blue area in contrast to the surrounding brown/yellow/grey areas. This is the same colour hue that appears for the unit (IX). The white patches observed are a bare ground of gentle mound topography. In the field the unit (IX) is noted formed of a scanty vegetation of <u>balanites aegyptiaca</u>, <u>caparis</u>

fascicularis, solanum orondo and several varieties of acacia, mainly acacia seyal. Also conspicuous is a tall savanna grass (Plate 12 (b)). Here the termites have developed termite mounds that are of black cotton soil. This soil type abruptly changes to a red sandy loam and is conspicuous on the road surface and the many termitarium. The contrast in this soil type and the black cotton soils is further enhanced by the presence of red termiteria (Plate 17 (a)). Within the region covered by the red sandy soil a thicker vegetation of the kind noted in the black cotton soil terrain was noted. However, the savanna grass is markedly short and there is a thick undergrowth of ipomea kituensis (Plate 12 (a)).

The mixed reflectance from the vegetation cover and the soil type gives a characteristic spectral signature that is unique for each area and thus for each unit. And even at the same locality as at locality K20, about 2 km north of Sajiloni market a slight variation can bring about spectral contrast which was used for boundary delineation in this area.

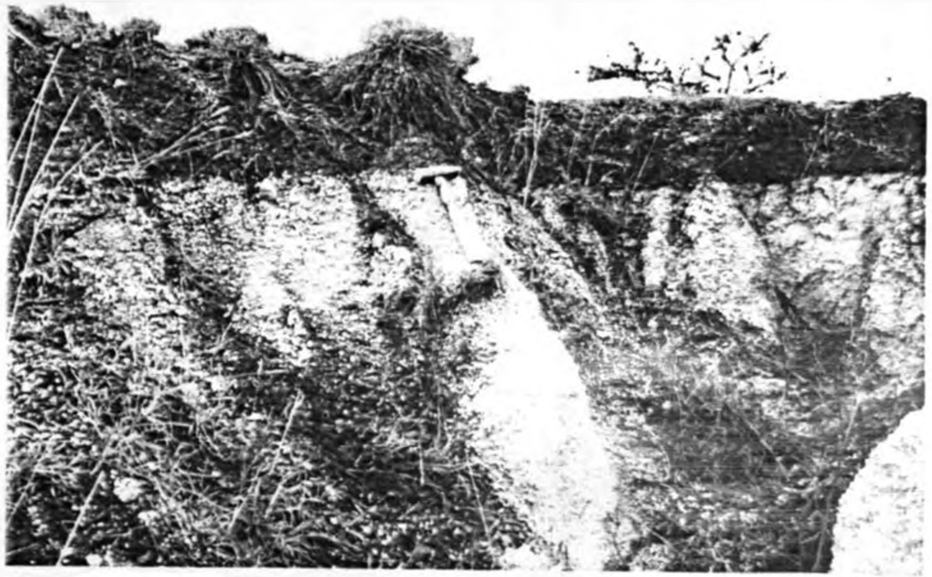
4.3.3.3 Precambrian Metamorphic Rocks

The rest of the area is covered by the Precambrian metamorphic rocks. These are deeply dissected by streams marked by lines of trees that show on the images as dark brown lines with a dendritic pattern. All the streams carry no water for the longer period of the year. During this period the river beds are covered by sand or exposed

(A)

Plate 12: changes in soil composition. (a) A red termitarium with the area marked by a dense growth of ipomea Kituensis shrubs and a short savanna grassland. (b) A black termitarium, there is a marked absence of Ipomea Kituensis. Note the tall savanna grassland and the Solanum Orondo shrub on both mounds. (c) A thin cover of black cotton soil over deeply weathered gneisses. Note the single acacia drepanolobium tree. (d) At the same locality as (c), K65 A thin cover of phonolite is noted.

(C)



(D)

rock outcrops (Plate 13 (c) and (d)). The sand and bare rock give a highly reflective surface and despite the riverine vegetation along the banks of the river (Plate 13 (c)), the large spectral difference between the river bed and the vegetated banks show up on the image as bright lines between the dark brown shading on the river banks.

The drainage pattern coupled by the brown yellow colour hue was used in delineating the remote sensing unit (I). The unit is mainly a quartz-feldspar gneiss of the Precambrian age. It is covered by a thick red soil. In certain localities (plate (c)) the streams have eroded into the soil exposing the rock. The quartzo-feldspathic gneisses vary greatly over the area. They are all highly foliated with the foliations formed by layers of different mineralogical composition and marked by a preferred orientation of platy minerals especially mica.

Among the quartz-feldspar gneisses are lenses of crystalline limestone and quartzites that are well developed and mappable on the image. The limestone on the Ilemelepo Hills, located to the west of the area is quite conspicuous and was noted in the field intercalated with quartzites. There are numerous other smaller crystalline limestone outcrops within the quartzo-feldspathic gneisses that are poorly exposed. They could be traced on the image as lensoidal units forming ridges. The surface of this unit was represented by kunkar limestone that at the river valley, locality K25, appeared to form a more crystalline limestone. The larger crystalline limestone occurrences

(A)

(B)

Plate 13: Four stages of river valley development. (a) Sinuous streams deeply cutting through the upper slopes of the Precambrian metamorphic terrain. (b) An erosion gulley in a soft sandy soil. A soft gneiss is exposed at the gulley bed. (c) A dry river bed exposing foliated gneisses and pockets of sand. A riverine vegetation at the bank of the river is evident. (d) A thick sand exposure in a wide river bed and flood plain. The sandy surfaces are very reflective and therefore quite conspicuous on the images.

(C)

(D)

are mined at the Kenya Marble Quarries. These major limestone occurrences are not thick bands, but several smaller bands of limestone with numerous silicons and calc-silicate intervening layers.

To the south central parts of the present area, the area rises into a number of hills with the Ngoragaishi Nasha, and Olpusi Moru, the most prominent. On the image these hills appear to be bordered by a belt of bright yellow/brown zone marked as the unit (III') and occupy the lower slopes of what appears to have been a large mass of hill that has now been dissected into smaller hills. These hills form the unit (III). Field evidence showed that the two units are composed of augen gneisses outcrop (Plate 17 (c)). This unit extends into the southern boundary of the study area and appears embedded into the quartzo-feldspathic gneisses. At locality K27, the preferred elongation of the auger gneisses is N86^{o}W. As is evident in plate 17 (c) the augen are easily visible macroscopically. They vary in density from locality to locality. The rock is highly resistant to erosion and so tends to occur as hills.

4.3.4 Geological Image Interpretation of the Yatta Plateau - Kanzalu Range Area (Plate 14 & fig. 14)

4.3.4.1 The Structural Geology and Lithology of the Kanzalu Range Area

The area shown in Plate 14 covers the north eastern corner of the study area. This FCC of the TM image of 27 November

Plate 14 —
The Yatta Plateau (1) forms a linear feature striking N45 ° W. The other linear features are the strike on the Precambrian metamorphic grain that on the plateau is N45 ° W, Kanzalu range and the units (2) and (3) N27 ° W and else where N 12 ° W and N-S (see figure). The crescent like feature (5) are the irrigated coffee plantations around the Yatta Farrow. Note the white cloud (6) and its shadow and how they obscure ground features.

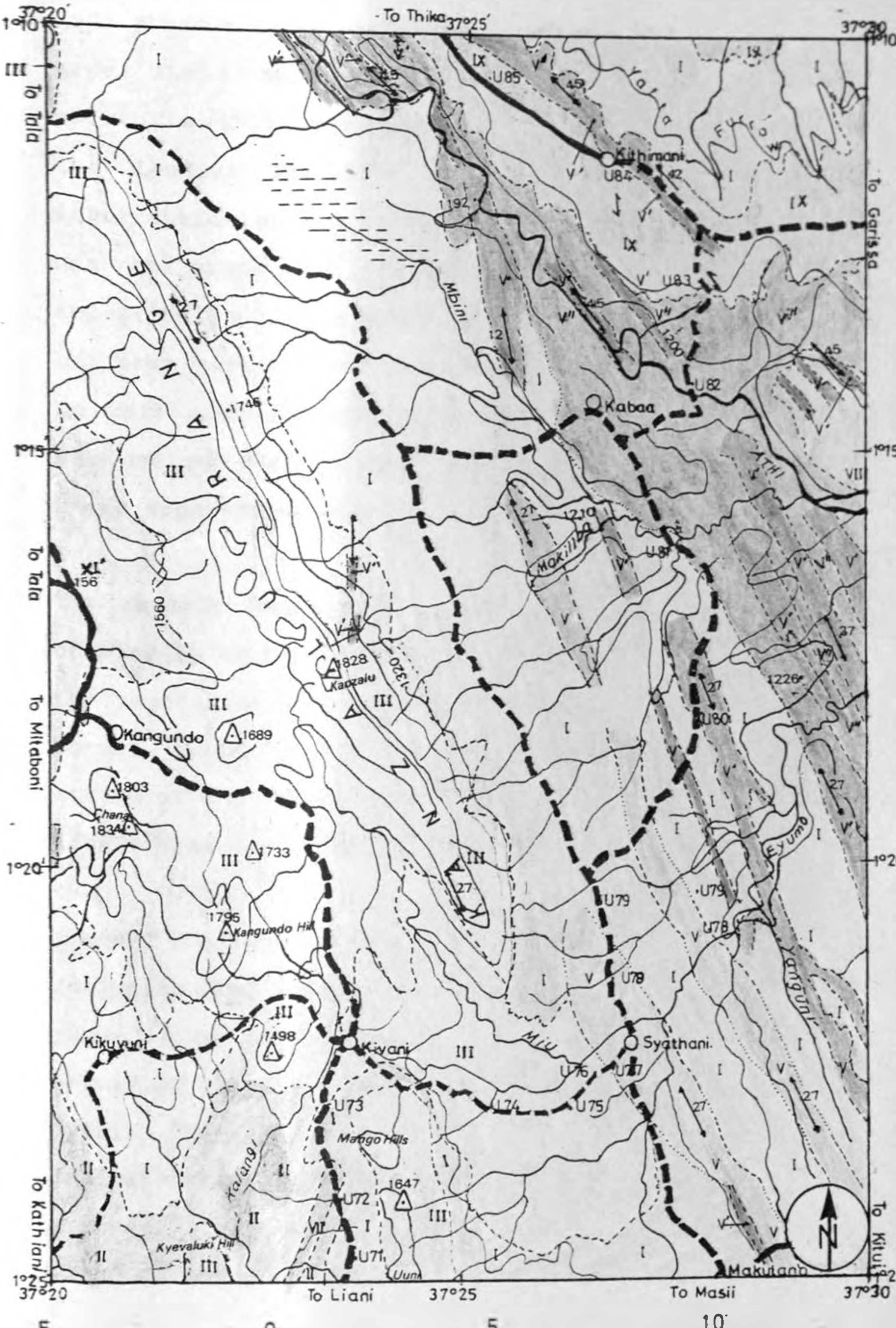


Figure 14 - The Kapiti Phonolite (IX) forms a scarp against the biotite gneisses (V") to the south. The near white linear features on the image are the pegmatitic biotite gneisses (V') and brown/yellow ones are hornblende-biotite gneisses (V). The ridge forming the Kanzulu range is of granitoid gneisses (III); the unit can be traced to Kyevaluki and Mango Hills. A band of crystalline limestone (VII) is an intercalation in pelitic gneisses and schists with muscovite-biotite gneisses, thin quartzites and graphitic gneisses (II). The welded tuff (XI') were mapped in the field.

1985 shows a large variation in structural pattern in this area. The linear feature (7) running across the image at about the $1^{o}15'$ latitude is a filled up gap left out by the Landsat satellite for this period. Despite its interruption on the continuity of data for this area, it has no structural significance. The cloud cover (6) appearing as fluffy white with a black shadow to the west obscures part of the image to the north west of Kangundo. In this area interpretation from this FCC is difficult. The use of MOMS-01 image of 27 July 1985 helped offset these apparent hindrances to data interpretation.

The Kanzalu Range area (4) is a largely vegetated area showing up on the image as bright red to brown. Apparently the vegetation has a high chlorophyll value. Despite this forest cover, structural patterns show up clearly. The strike of the structural pattern on the main Kanzalu Range is $N27^{o}W$ as measured from the image.

The $N27^{o}W$ striking linear patterns represent the strike of foliation and banding in the metamorphic terrain. The range is probably a relic of an anticlinal fold covered mainly by granitoid gneisses of Precambrian age (Fairburn, 1963). The presence of foliation in these gneisses indicate that the metamorphism and deformation were not as intense. The foliation represent the primary structural trend of the original sedimentary rocks.

To the south of the Kanzalu Range the tone is marked by a dark brown to grey/green colour hue. The area is highly dissected by river valleys that are largely controlled by the slope of the hills and the underlying rock. On the image the streams are not conspicuous because of the shadow effect from the numerous hills. Of these hills Mango Hill is of particular interest forming a ridge striking N20^{o}W and appears in dark brown to grey/green colour hue due to the low chlorophyll vegetation covering the hill. Field investigation points to the presence of a migmatite tending to a granitoid gneiss. To the west of this hill the crystalline limestone delineated at U64 and U65 near Kaani Market on Machakos-Masii road and at U45 on the Masii-Tawa road - Thwake river junction, to the south of the present area, could be traced northwards. In the present area it is represented by the unit (VII).

This limestone is intercalated between the unit (II), which extensively covers the area around Kalangi and Thwake river to the south. On the FCC it appears in green colour hues but is more conspicuous on the black and white MOMS-01 image. On this image the unit appear as a dark grey zone closely following the trend of the Thwake and Ikiwe river valleys and their tributaries. It would appear that the unit (II) structurally control the flow of these rivers probably following the strike of foliation in the unit. Field observations revealed that the unit is an intercalation of pelitic gneisses and schists with muscovite gneisses and thin graphitic gneisses and quartzites. These gneisses and schists are relatively thin and could not be mapped as single units at the scale of the present map. They are highly foliated and impart a striated appearance to the image. The foliations represent relic structures of bedded sedimentary rocks of contrasting lithology. In zones where metamorphism was relatively intense the foliation is represented by thin slabs of hard gneisses tending to granitoids in composition (Plate 15 (b)). In other localities the metamorphism has resulted in soft schists and gneisses that highly reflect the original composition and trend of sedimentary bedding (Plate 15(c)). As is evident in Plate 15 (b)the river bed in the foreground runs parallel to the strike of foliation and is thus structurally controlled.

Along the eastern parts of the area shown in Plate 14 banding or bedding has also imparted a topographic grain expressing parallel alignment of ridges and low areas due to differential weathering. The bands probably represent relic structures of bedded sedimentary rocks of contrasting lithology. Foliation in the metamorphic would give a similar appearance. On the image the banding is represented by striations of light to white areas (V') representing the ridges and striking N27^{o}W. The low areas (troughs) (V") are represented by dark striations of green with light brown or yellow tints trending in the same direction. This is the same trend as that noted on the Kanzalu Range. On the full scene imagery of the area these striations are more conspicuous to the south east and show the same consistent strike.

Field observations showed that the surface is made of gneisses Precambrian. To the south of Athi river is the

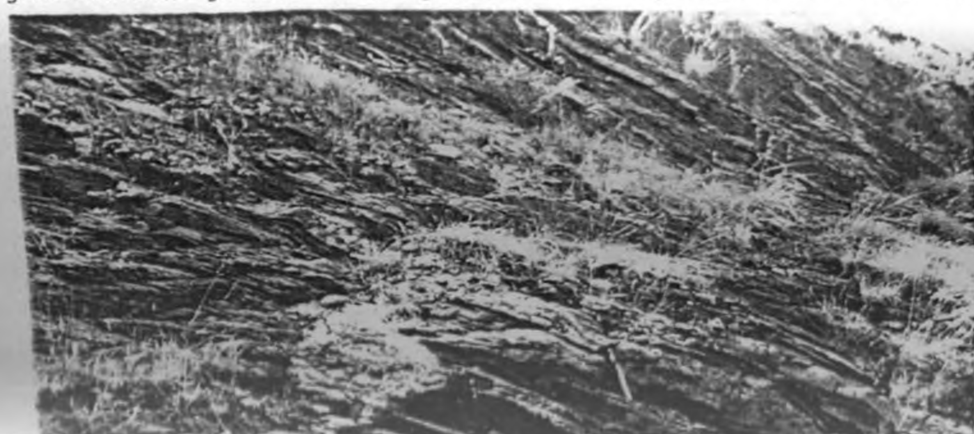
Plate 15: Structures in the gneisses of the Precambrian metamorphic terrain. (a) An unconformity between pegmatitic biotite gneiss and the Yatta Plateau Phonolite, the gneiss is an inlier in the phonolite. The phonolite has weathered into laterite.

(A)

(B)

(b) Foliated quartz-feldspar gneiss. (c) Foliations of thin quartz-feldspar gneiss with graphitic gneisses and schists. (d) Massive granitoidal gneiss showing relic bedding represented by the banding.

(C)



(D)

surface of long ridges separated by narrow flat bottomed minor valley floors with occasional rivers.

In the area shown in Plate 14, streams emanating from the eastern slope of Kanzalu range flow eastwards in short parallel drainage pattern. The drainage lines are defined by bright lines representing the sandy stream beds. Much of this pattern occupies the region that shows a marked absence of the striations on the metamorphic rocks. A different remote sensing unit (I) was delineated for this region. Field investigations revealed a bare soil cover with very few rock exposures. The area is generally flat and many different types of gneiss outcrops characterize the area. Towards the east of this and bordering the plateau are the biotite gneisses (V) which show up in darker green/grey with same yellow colour hue.

4.3.4.2 The Structural Geology and the Lithology of the Yatta Plateau Area

The Athi river flows closely along the foot of the scarp marking the south-western edge of the Yatta Plateau. The Yatta Plateau itself is a long narrow plateau with gentle depressions showing up on the image as dark to dark blue spots. These spots give the Yatta Plateau unit (IX) a stippled appearance. The unit (IX) itself shows up on the FCC image as a green/yellow colour variation with a bordering scarp to the south west. The scarp shows up in a dark brown colour hue. This colour is due to the shadow effect and a mixed reflectance from the rock boulders and increased vegetation occupying the scarp. The scarp is also strongly dissected.

The lava flow forming the plateau is 3 to 5 km wide and is over 200 km long. It strikes in a south east direction into the adjacent area. Matheson (1966), Fairburn (1963) and Baker (1952) suggest that the lava is about 15 to 25m thick at the edge and lies on the sub-Miocene surface cut on the gneisses. They imply that the lava is probably a remnant of a much more extensive lava flow with the underlying gneisses sloping gently to the south east along the line of the plateau.

The use of MOMS-01 and Landsat-TM data show significant details about the Yatta Plateau. Striations striking N45^{o}W on the plateau are evident. They appear to be a continuation of the strike on the Precambrian metamorphic rocks. Field evidence showed this as an exposure of pegmatitic biotite gneisses (Plate 15 (a)). This bare rock formed a ridge like feature that is exposed through erosion of the overlying phonolite. In this locality, U84, the phonolite is represented by a thin capping of laterite. The dark brown exposure in plate 15(a) is the laterite capping over the pegmatitic biotite gneiss that appear very bright. The strike of elongation of ferro-magnesium minerals measured in this locality is N42^{o}W. This is in close conformity with the trend of the striations on the plateau as measured from the image.

As is evident on the images, especially the MOMS-01 image that covers a greater area to the north and east of the present study area and is evident on the black and white Landsat-3-MSS image, the striations north of the Athi River show a variation in trend. Their trend is closely parallel to the plateau at the surface (trending N45^{o}W) and changes progressively to strike N27^{o}W in the area further north. The synoptic view would suggest that there has been some tectonic movements largely effecting the area north of the Athi river. The effect is confined to the Yatta Plateau and the area close to it. This trend variation would suggest a movement along a north west, south east trending fault with the northern eastern block moving right lateral relative to the southern compartment. A strike slip fault is suggested as shown in figure 15.

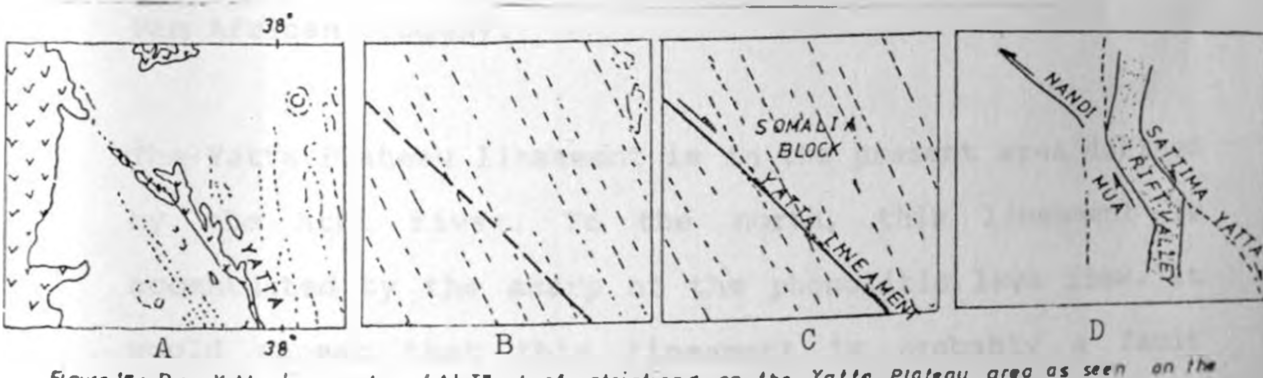


Figure 15: The Yatta lineament. (A) TTend of striations on the Yatta Plateau area as seen on the satellite imagery. (B) Undisturbed trend of striations in a stable Mozambique Belt with a possible position for the development of the yatta lineament. (C) Possible south east motion of the Somalia Block resulting in a strike slip movement along the Yatta lineament leading to the change in strike of the Precambrian striations close to the lineament. (D) Schematic tectonic interpretation of Cenozoic reactivated, structures. (reference: Chorowicz et al, 1988)

Chorowicz et al (1987) points out that the geometry of deformation and the mechanism of the Cenozoic intracontinental deformation of the East African Rift implies a near NW-SE movement of the Somalia block relative to the African continent. The stress so created could have caused the fracturing that lead to the Aswa lineament. The south east motion of the block could also be responsible for the variation in trend of the Precambrian metamorphic grain, that shows the lithologic trace in the north eastern compartment progressively turn in strike to become parallel to the Yatta Plateau.

In his study of the Aswa lineament Chorowiz et al (1988), indicates that the lineament is a Heogen intracontinental transform fault zone trending north west, south east. The lineament is an "en echelon" fault and links the western and eastern branches of the East African Rift Valley. Its continuation in the eastern branch of the Valley is represented by the Yatta Plateau lineament. He suggests that in the formation of the Yatta Plateau lineament, a frontal and lateral ramp system was generated due to the resistant block formed by the Tanzanian Shield during the Pan African Orogeny.

The Yatta Plateau lineament is in the present area defined by the Athi river. To the north, this lineament is accentuated by the scarp of the phonolitic lava flow. It would appear that this lineament is probably a fault through which fissure eruption of the Yatta Phonolite lava flow took place. The north eastern facing scarp of the Yatta Plateau has been eroded away. This gives way to the Precambrian Metamorphic terrain shown as unit (I). On the image, the reflectance value of this unit is similar to that located just east of Kanzalu Range. However, this is interrupted by the vegetation showing up as a semi-circular feature in bright red. These are the coffee plantations (5)along the artificial Yatta Farrow. The plantations are irrigated fields of the National Youth Service Farms at the Yatta Field Unit.

4.3.5 Geological Image Interpretation of Machakos-Mbooni Area (Plate 16 and figure 16)

This area is characterized by high hill masses that are relatively steep. The summit plan of the hills is closely dissected into a series of closely spaced rounded ridges and spurs separated by numerous narrow valleys. the summit levels are at between 1700 m to 2100 m above sea level. Some of the stream valleys are erosion gullies of the type indicated in Plate 13 (b). At the youthful stage of the rivers (Plate 13 (a) and (b) erosion is evident. The loose sandy soil and rock material are redeposited in the river beds at their mature stage. At this stage the sinuous rivers open into a wide flood plain (Plate 13 (d)). Many of the small rivers that arise from the hills are not visible on the imagery, either due to vegetation cover or shadow effect. The characteristic alignment of vegetation along the rivers as was noted in the volcanic terrain is also absent. The major rivers are defined by a white line representing the highly reflective sand surface covering their beds.

The cultivated Mbooni forests on Mbanya and Mbooni Hills and Kalama forest on Kalama Hill appear as near bright red features on the FCC image. Small grooves of the forest are also evident on various parts of the hills. Field investigations revealed these forests to be of Eucalyptus

Plate 16 —
Three major trends of the Precambrian metamorphics can be recognised. Mbanva Kalama Muumandu correlate with Iveti and strike N34° W as does Kyandili, Kyanzimbi and Wamui rivers. The red hue on the hills is due to cultivated vegetation (wattle, euclyptus, and food crops). Natural vegetation is in dark brown to black where dense and yellow brown where scattered. Other strikes closely follow the trend of Ikiwe and Thwake rivers.

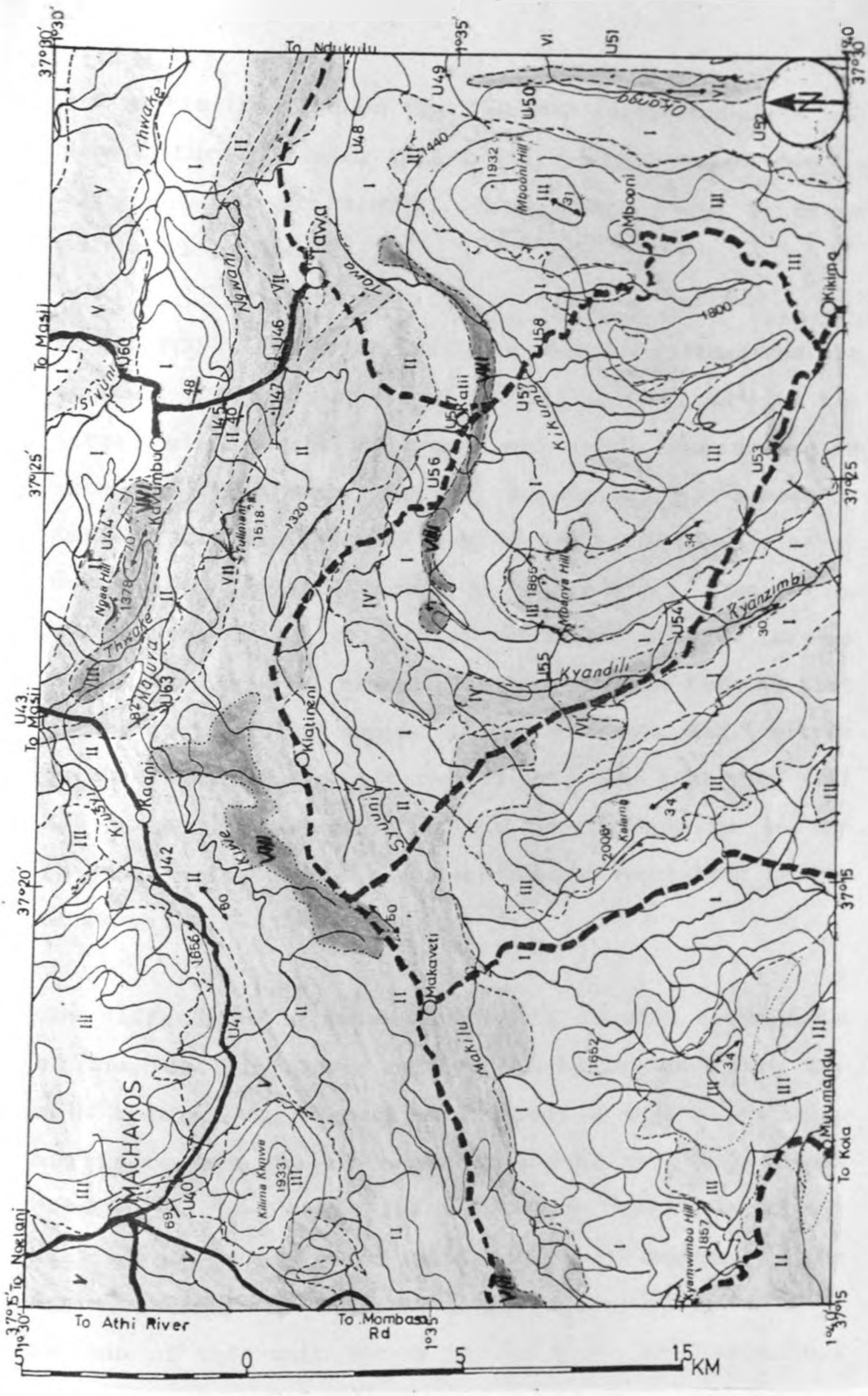


Figure 16 - The parallel hill masses together with Mbooni and Kilima Kimwe bear granitoid gneisses (III). On the lower slopes they are highly foliated giving way to undifferentiated Precambrian metamorphics (I). The crystalline limestone (VII) is sandwiched between pelitic gneisses and schists with muscovite-biotite gneisses, thin quartzites and graphitic gneisses (II). A quartz vein (VI) run in a North-south direction, east of Mbooni. Quartz-feldspar hornblende gneiss (IV') and an amphibolite hornblendite (VIII) curve around the Mbooni. All the rock units even the biotite gneiss (V) control the drainage pattern.

and wattle trees. These together with cultivated crops and some natural forests thrive well on the hills due to higher amount of rainfall. They impart a red to brown colour hue to the hills.

In the FCC of Plate 16, four main spectral differences are eminent. The hills show two spectral differences with the larger hill masses of Mbooni and Iveti showing up in bright red to brown colour hue. The smaller hill masses of Kalama (2006 m), Kyamwibo (1857 m) and Kiima Kimwe (1933m) showing up in dark brown to brown/green area. This differences is due to lack of cultivated forests (trees) on the smaller hill masses. The local people have it that attempts to plant exotic trees have met difficulties because they dry soon after or if they take root they will dry at a later stage. Thus the two differences in the spectral values reflect differences in vegetation health on the hills.

The differences in vegetation health is more conspicuous on the low lying areas between the hills. Here too, two main spectral differences were noted. A dark green/brown hue represents the low areas bordering the main rivers especially along the Ikiwe and Thwake rivers. A bright yellow/green area with a white background represents the areas immediately bordering the main hills. Another portion of this unit occurs to the south of Isivuni and Thwake rivers east of Ngaa hill.

The spectral differences are further enhanced by a marked low rainfall registered in the area between the hills. The critical problem in this area is soil erosion when the rain storm does come. This washes away the bare soil that is hardly protected by the sparse vegetation. These compounded effects makes the area poor for agricultural activities. This is evident on the image where the characteristic spectral signature of cultivated areas is absent. Thus this area present a natural set up where the vegetation reflect differing growth conditions induced by the chemical and mineral concentrations in the soil which are a direct derivative of the underlying rock.

The Mbooni hill (figure 17) bear a peculiar structure shaped like "an animal head with horns". The "horn" like protrusions to the north represent Mbanya hill in the west and Mbooni hill in the east.

This feature is further enhanced by Kyandili (drains to the north) and Kyensimbi (drains to the south) river valleys. They more or less parallel the foothills of the

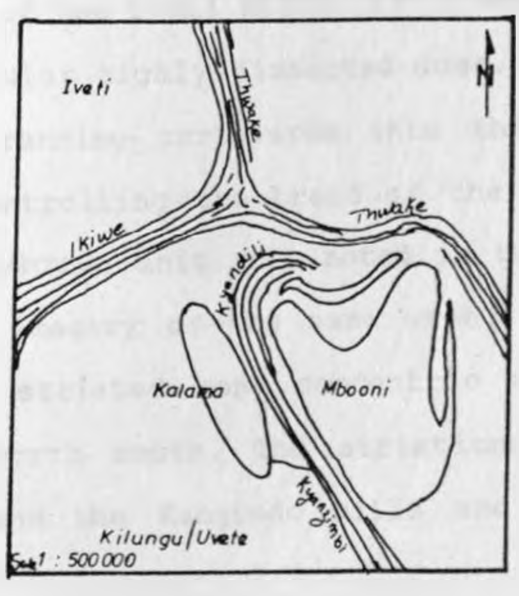


Figure 17 - Structural patterns around the Mbooni massive.

hills and are bordered to the east by a positive relief linear feature (IV) trending N30^{o}W. This ridge like feature was investigated in the field and found to correspond to a quartz feldspar hornblende gneiss. To the east of the hills the foothills were also enhanced by the Okanga river that flows northwards and bordered to the east by a positive linear feature that structurally control the trend of the river for some distance. The feature correspond to a quartzite (VI) trending north south. These structural features curve in around the hill to the north and south to take the shape of the hill. On the image another positive relief (VIII) is suggested. Field investigation showed this unit to be an amphitolite hornblendite.

The Mbanya hills (1), and further west the Kalama hills (1") are elongated and were noted trending N34^{o}W. This is in close proximity to the trend of the striations noted on the Precambrian metamorphic terrain to the north east of the present area and discussed in Section 4.3.4.

A portion of the Iveti Hills (1"') shown in Plate 16 form a sub-circular highly dissected dome. To the east of this dome and running northwards into the adjacent area and closely controlling the trend of the Thwake river is the dark green/brown unit (II) noted in the FCC. In the black and white imagery of the same area, this zone appear as dark grey striated zone concentric around the hill and striking north south. The striations continue north to curve around the Kangundo hills and disappear into the volcanics located to the west of Kangundo. To the south of the Iveti dome the striations appear to strike N60°E and run parallel to the Ikiwe and Maluva rivers. It changes direction at the confluence of the Maluva and Thwake to follow the trend of Thwake eastwards. Here this zone takes the general shape of the northern edge of the Mbooni dome.

Intercalated between the remote sensing unit (II) are the units (IV) and (VII) that appear in slightly lighter green/brown colour hue against the dark green/brown surrounding area. Field observations indicated that the unit (II) was mainly of pelitic gneisses and schists largely represented by thin bands of quartz-feldspar gneisses, muscovite-biotite gneisses, quartzites and quartz-feldspar-hornblende gneisses (plate 17 (a)). Sometimes the unit shows quartz intrusions and numerous other banding including graphitic schists. Intercalated between these units are two broader bands of amphibolite hornblendite and crystalline limestone band noted closely following, for considerable distances, the trend of the other bands that define the unit (II). The limestone appear as bands separated by thin bands of graphitic schists, micaceous schists and quartzites. These thin bands separate three types of crystalline limestone that differ in colour. The white variety is located to the east end, the grey banded variety is in the middle and the dark grey variety towards the west (plate 3 (c) and plate 4 (b)) at locality U63 and U47. Large blocks of the white and banded varieties were being mined on the surface using hand tools. The blocks are loaded to the

(A)

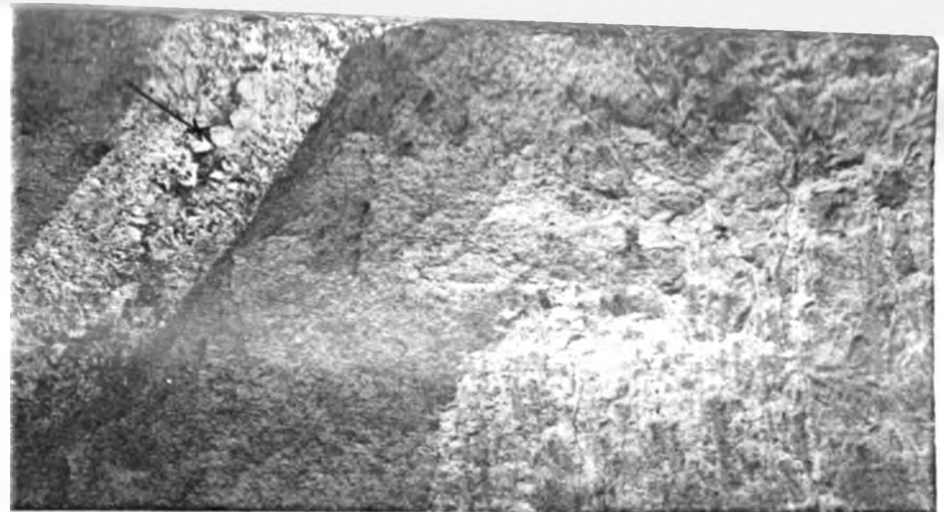


Plate 17: Gneiss exposures in the Precambrian metamorphic terrain.(a) Thin bands of (from left) quartz-felspar gneiss, biotite-muscovite gneiss, quartzite and quartz-felspar-hornblende gneiss.(b) Soft micaceous biotite gneiss with a poorly metamorphosed

(C)

(D)

limestone intercalation. Note the quartzite (arrowed).(c) An augen gneiss outcrop showing dense macroscopic augen. (d) A highly jointed quartzite that has been mined for road aggregate. The water is due to a fill from rain run-off.

lorries and transported to Nairobi for cutting and polishing to form highly decorative marble tiles. The dark grey marble was being mined for fertilizer. This was broken into small chips and transported by lorry for lime manufacture.

Along the Masii road of Isivuni river a biotite gneiss was noted. On the image the gneiss extend eastwards in a strip 2.5 km wide and is boarded to the south by the Thwake river. On this FCC, the unit appears in stripped lighter green with some yellow/brown tint.

The type area shown in Plate 16 continues south with a few important structural variations. Broadly, the area is characterized by several circular massive domes with Kilungu, Uvete, Mbatini, Nguuta and Kilima Kyakatoni the most conspicuous. The domes form a rugged dissected terrain cut by numerous streams pronouncing prominent spurs running down the hills. Two prominent spurs are particularly noted on Kilungu hills forming the Kilungu forest and Inyokoni hill. The two spurs strike N35^{o}W and N40^{o}W respectively. They structurally control the Nthiani and Kyangonyo rivers. At this trend they appear to be in conformity with the strike of the Precambrian metamorphic grain noted to the north in the adjacent area.

The slight spectral differences noted among the hills and the intensity of dissection by streams and rivers would indicate on the image that the Kilungu dome in comparison to the Uvete dome to the south are composed of different units. A field survey indicated that the mass of Kilungu Hills are formed of a soft micaceous biotite gneiss that has intensely been deeply dissected by stream valleys. The micaceous biotite gneisses are extensive are, in numerous places, intercalated by poorly metamorphosed limestone bands that have quartzite intrusions in them (plate 17 (b)). Where there is a larger occurrence of the limestone it is, being mined for local plastering of house walls and mixed with clay soil to burn bricks.

The Uvete dome on the image shows a marked absence of vegetation and is less dissected by streams. On the image the lower slopes of the dome appear smoothened out and rather gently sloping. The dome structurally controls the Wautu and Makuyu rivers. The unit (II) is concentric around the dome. The unit (II) could not be traced further south and disappears, most likely into the volcanic soils in this area.

Field observations made on the Uvete dome revealed an exfoliated granitoid gneiss forming the dome. The gneiss covers a very extensive area. It still largely bears the banding (plate 17 (d)) that are a relic of the original bedding of the sediments from which it was derived. The trend of the bands as measured at locality U22 and U23, was N44^{o}W. The Uvete dome is relatively lower in altitude than the surrounding hill masses. Further south into the area near Kasikeu a similar banded granitoid gneiss was noted although its trend measured in the field was N25^{o}W. An important exception to this north west general trend was of the banded granitoid gneiss at locality U6 just south of Wautu. This showed a north easterly trend (N30°E), the same trend as the amphibolite intrusion trend noted at locality U7 to be N28°E. The intrusion is extensive and on the image it can be located running for considerable distances. The unit dips 68° to the north east and literally measured 1 Km thick.

South of Mbatini Hills the terrain breaks into a relatively flat area characterized by short drainage lines that arise from the Mbatini Hills and quickly disappear into the volcanic soils and Recent alluvial deposits covering this part of the area. The volcanic soils are derived from Muaani and Kalembwani volcanic cones that bear shallow craters. The volcanic material from both the hills cover a larger area to the south, outside the present study area. However, their occurrence in the present area could easily be traced out both from the FCC where it shows up in characteristically blue/grey or green colour hue, and on black and white imagery where it shows up as a dark grey uniform colour tone. The volcanics are vesicular olivine basalts. They are Pleistocene in age (Baker, 1954) and form the north western representatives of the Chyulu basalt ranges.

CHAPTER FIVE

5. RESULTS AND DISCUSSIONS

5.1 Geological Mapping.

The first objective of this study set out to examine the effectiveness, suitability and capacity of satellite data for geological mapping of the Nairobi - Kajiado-Machakos Area. From the analysis of standard false colour composites (FCC) of Landsat - 5 TM and Landsat - 3 MSS; and black and white Landsat - 3 MSS and MOMS-1 MSS imageries, surface geological units and structures were separated. The separation of the units and structures was based on three measurable or recognizable features:

(1) Geometric shapes, forms and patterns.

(2) Textural Patterns.

(3) Radiometric and spectral signatures.

The area was divided into two broad divisions, the volcanic terrain and the metamorphic terrain on the basis of interpretation from radiometric and spectral signatures in the FCC. In the composites the volcanic terrain appeared in the grey/blue colour hues and the metamorphic terrain in the yellow/brown colour hues.

5.1.1 The Volcanic Terrain

In geologic interpretation of the volcanic terrain, geometric shapes, forms and patterns were exploited in delineating lithologic unit boundaries and structural features. The linear features recognized from a series of dark parallel lines trending in a north-south direction (plate 7 and mapped in figure 11) are faults associated with faulting and tectonic activities in the rift valley to the west of the study area. The lava flows were mapped from the lobate patterns (plate 2 and mapped in figure 9 and plate 7 and mapped in figure 11) and tonal contrast due to abrupt topographic changes, vegetation changes and rock-type changes. Scarps such as that forming the edge of the Yatta plateau phonolite (plate 14 and mapped in figure 14) were similarly recognized.

5.1.2. The Metamorphic Terrain

Geological features in the metamorphic terrain were mapped from characteristic radiometric and spectral signatures, topographic texture changes and drainage pattern. The series of parallel dark and bright zones (plate 14 and mapped in figure 14) trending in north west - south east, are foliations and banding in the Precambrian metamorphic gneisses. The foliations and banding represented the primary structural trend of the original sedimentary rocks. Each dark or bright zone represented a characteristic lithologic unit that was identified from supplementary field mapping.

Most of the hills in this area were recognized from their high relief. The high relief implicated the presence of resistant rocks which were mapped in the field as granitoid and augen gneisses. The Kilungu Hills showed a more dense drainage pattern than the rest of the hills and was mapped as soft muscovite-biotite gneisses. The Ilemelepo Hills although standing the same height as the rest of the hills, showed a variation in its texture and colour hue. They are composed mainly of intercalations of quartzites and marble.

5.1.3 The Geological Maps

The second objective set out to prepare a synthetic geological map of the Nairobi - Kajiado - Machakos area. The interpreted geological and structural units were compared with the existing geological maps of the area and other ancillary data such as the land system unit atlas, In certain localities more details showed up on the image (e.g. plate 14 and mapped in figure 14) than was presented in the geological maps. Six imageries were used to ascertain the consistency of the image features used to delineate the unit boundaries. In naming the units ancillary data such as geological maps of the area, topographic maps and the land system atlas were used. This would justifiably be regarded as a deliberate bias. It, however, could not be totally avoided although extensive field ground truthing was carried out to justify the named lithological units. The field verification check of the interpreted units supplemented the collateral information mentioned above and served to determine the accuracy of the interpreted geological map. All the data was compiled to produce a synthetic geological map of the area (pocket map). Five other synthesized geological maps representing selected sections of the area (figures 9, 11, 13, 14 and 14) were produced from a detailed analysis.

The geological units shown in the geological maps of the area are based on the smallest measurable linear dimension of approximately 1mm. At the mapping scale of this study 1:125000, it represents a mapping unit of 125m. The satellite's smallest mapping unit is the pixel (80m for Landsat mss data, 28m for landsat TM data and 20m for MOMS - 01 MSS data). Satellite mapping approach was found to have potentially more information due to its smaller mapping units than those shown on the geological maps. The detectability of small units was enhanced by large radiometric signature difference between materials. Representative spectral values were interpreted and selectively examined in the field. Extrapolations were then made to the adjoining areas using the image. This way broad areas were rapidly mapped by delineating similar remote sensing units. Areas within these units which showed significant tonal contrast and topographic texture were field checked to ascertain their lithology. This discrimination of areas was a deliberate bias and helped in minimized and optimized field work. Thus satellite data mapping approach was found to be cost effective and time efficient as a geological mapping tool.

5.1.4 Land use Characteristics

The third objective set out to evaluate the land resources of the area such as vegetation resources, hydrogeology, settlement pattern and demographic pressure. Many of the geological features observed in the area were largely confined to influence of vegetation and soil cover type. The composition of residual soils of the area reflected the composition of the underlying rocks. In the areas where there was little influence of human settlement, the soil held a vegetation that was specific. Here the interpretation of the remote sensing units and their geology followed from the radiometric signature recognition. Comparison was made with ancillary data and field checking made to attach a meaning to the mapped remote sensing units. The meaning of the these units provided thresholds of information for the final radiometric signature classification.

South and east of the study area, individual local, isolated and small areas have been settled and cleared for cultivation. These areas showed no frontal massive boundary change and thus did not influence the overall radiometric signature values.

In the area to the north west there are large human settlements. The natural forests have been intensively cleared to give way to cultivation of cash and food crops. In the larger plantations especially of coffee, tea end sisal a boundary change defining the fields was observed on the images. In the small scale mixed farms, a mixed reflectance does occur, making it difficult to delineate geological features from the image. The presence of a large human settlement has resulted in increased communication infrastructures and the development of commercial centres, Nairobi being by far the largest of these centres, was easily delineated from the FCC from the bright blue colour hue. This spectral value can be exploited by town planners and engineering geologists by determining the direction of expansion of the town relative to the availability of construction materials, drinking water and other amenities

5.1.5 Errors in Radiometric Signature Classification for Geologic Mapping

Errors in radiometric signature classification as related to observations of the imagery of different periods were noted as:

(a) The solar azimuth was different for images of different periods. These differences carried errors related to differential illumination and shadow effect on the satellite data. Low sun angle illumination during imaging enhanced subtle geologic features.

(b) Seasonally related temporal changes offered significant errors. Cloud cover, scarred land from burning and cultivation, flush vegetation growth in response to plentiful precipitation were some of the changes that were observed. Multidate image registration was found particularly sensitive to the predominantly small and localized land cover changes. These helped in offsetting temporal changes that cause confusion in single image interpretation.

(c) Landsat-MSS data has a coarse spatial resolution. However, the spatial resolution of the TM and MOMS-01 sensors provided a good spatial aggregation. This greatly increases discrimination of small geological units. A coarse spatial resolution reduced discrimination of the geological units.

In summary, seven synthesized geological maps were produced and a cross-section drawn from the main map. The results of this study from satellite (Landsat-MSS, TM and Space Shuttle MOMS-01) remotely sensed data proved useful to some extent in mapping the geology of the Nairobi-Kajiado- Machakos area.

CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations may be made from this study.

1. Geological mapping using remotely sensed satellite imagery of the Nairobi-Kajiado-Machakos area is a

possible and useful approach. From the imagery data it was possible to identify four types of geologic data:

(1) The location and trend of major faults on the eastern shoulder of the Rift Valley.

(2) The location and trend of foliation and banding in Precambrian metamorphic rocks to the north east.

(3) Offset direction of the Aswa Transform Fault along the edge of the Yatta Plateau.

(4) Lithologic information in the form of radiometric signatures, topographic style and corresponding image feature.

2. Producing a geological map by visual image analysis is cheap and quick. From the radiometric signatures it was possible to define broad grouping of rock units owing to differences in lithology and in associated vegetation which provided distinctive colours. The colour identifiers were used to pick out and map the same remote sensing units elsewhere. A large number of remote sensing units corresponded to lithologic units and were detectable to a large extent by visual analysis of satellite imagery. The correspondence of satellite viewed surface geological patterns with those in previous geological maps is self evident.

3. Certain drainage patterns were found to be confined to single lithologic units. The patterns were used in mapping the units The parallel drainage pattern at Loo Ntepes area was confined to the Ol Doinyo Narok agglomeratic tuffs; the near radial drainage pattern

of Nairobi area to Nairobi Phonolite; the parallel drainage pattern to the north western corner of the area to the tufficeous rocks; and the pinnate pattern in Ol Doinyo Narok area to Ol Doinyo Narok agglomerates.

4. Lithologic contacts on imagery were extended over large areas with a minimum of ground control. Identified rock types were extrapolated on the basis of radiometric and geomorphological information. The regional perspective enabled the same units to be extended into the adjoining areas

REFERENCES

Andrews, H.C. and Hunt, B.R. (1977), Digital Image Restoration. Prentice-Hall, Englewood Cliffs: New Jersey.

Baker, B.H. (1954) Geology of the Southern Machakos District: Report No. 27, Geol. Surv. Kenya.

Baker, B.H.; Williams, L.A.J.; Miller J.A. and Fitch F.J. (1971): Sequence and Geochronology of the Kenya Rift Volcanics. Tectonophysics V.II, pp.191-212.

Baker, B.H.; Mohr, P.A. and William, L.A.J. (1972): Geology of the Eastern Rift System of Africa. Geol. Soc. Am. Spec. Paper, pp. 136-167.

Bear, L.M. (1952): A Geological Reconnaissance of the area south east of Embu. Report No. 23. Geol. Surv. Kenya.

Bernstein, R. and Ferneyhough, D.G. (1975): Digital Image Processing: Photogrammetric Engineering. V.41 pp. 1465-1476.

Bhattarai, K.D. (1983): Mineral Exploration by remote sensing techniques in Nepal. Adv. Space Res. Vol. 3, No. 2, pp. 49-54.

Cahen L. and Snelling, N.J. (1966). The Geochronology of Equatorial Africa. North-Holland Publishing Company: Amsterdam.

Chorowicz, J.; Fournier, J.L. and Vidal, G. (1987). A model for Rift development in East Africa. Geological Journal Vol. 22, Thematic issue, pp. 495-513.

Chorowicz, J.; Guezlae, M.; Rudert, J.P. and Vidal, G. (1988): Analysis of the Aswa Fault zone in Kenya from Landsat MSS and MOMS-01 Space imagery. Influence of

Precambrian heritage on the Gregory Rift Structures. C.R. Acad. Sc. Paris t. 307 Series II p. 83-88.

Cole, M.M.; Owen-Jones, E.S.; Custance, N.D.E. and Beaumont, T.E. (1974): Recognition and interpretation of spectral signature of vegetation from aircraft and satellite imagery in western Queensland, Australia. Symposium European Earth Resources. Satellite Experiments, 1974 Proc. European Space Research Organization Spec. Pub. 100, pp. 243-287.

Crowther, A.F. (1957): Geology of the Mwingi area. Report No. 38, Geol. Surv. Kenya.

Curran, P.J. (1985). Principles of Remote Sensing. Longman Scientific and Technical. New York.

D'Hoore, J.L. (1977): Soil Diagnosis Through Remote Sensing in Earth Observation Systems for Resource Management and Environmental Control. Ed. Clough D.J. Plenum Press: London.

Dodson, R.G. (1953): Geology of the south-east Machakos area. Report No. 25, Geol. Surv. Kenya.

Fairburn, W.A. (1963): Geology of the north Machakos-Thika area. Report No. 59, Geol. Surv. Kenya.

Fillippone, W.R. (1986): Practical applications of remote sensing Geophysics. The leading Edge of Exploration, Vol. 6, No. 12, 1987, pp. 16-22.

Goetz, A.F.H. (1976): Remote Sensing geology - Landsat and beyond. Caltech/JPL Conference on image processing technology, Data Sources and software for commercial and scientific purposes, Jet Propulsion Lab. SP 43-30 P. 8-1 to 8-8.

Goetz, A.F.H. (1976): Applications of Remote Sensing for resource exploration, present and future; Jet Propulsion Lab.

Goetz, A.F.H.; Billingslay, F.C.; Gillespie, A.R. Abram, M.J.; Squires, R.L.; Shoemaker, E.M.; Luchitta, I. and Elston, D.P. (1975). Application of ERTS images and image processing to geologic problems and geologic mapping in North Arizona.

Gregory, J.W. (1896): The Great Rift Valley. John Murray: London.

Gregory, J.W. (1921): Rift Valleys and Geology of East Africa. Seeley, Service and Company: London.

Harris, R. (1987). Satellite Remote Sensing. An Introduction. Routlede and Kegan Paul: London.

Hunt, G.R. (1977). Spectral signatures of particulate minerals in the visible and near infrared; Geophysics V. 41 pp. 501-513.

Ilyin, A.V.; Glukhovsky, M.Z.; Koslov, V.V.; Moralev, M.V. and Startzev, A.L. (1983): The application of space imagery to geology and mineral exploration in the U.S.S.R. - A case history. Adv. Space Res. Vol. 3. No. 2, 1983, pp. 19-26.

Jourbert P. (1957): Geology of the Namanga-Bissel area. Report No. 39, Geol. Surv. Kenya.

Kowalik, W.S. and Glenn, W.E. (1987): Image processing of aeromagnetic data and integration with Landsat images for improved structural interpretation. Geophysics Vol. 52, No. 7, 1987 pp. 875-884.

Labovitz, M.L.; Masuoka, E.J.; Bell, R.; Siegrist, A.W. and Nelson, R.F. (1983): The application of remote sensing to geobotanical exploration for metal sulphides -result from the 1980 field session at Mineral Virginia. Economic Geology Vo. 78, 1983 pp. 750-760.

Lillesand, T.M. and Kiefer, R.W. (1979): Remote Sensing and Image Interpretation. John wiley and Sons: New York.

Lo, C.P. (1986): Applied Remote Sensing. Longman Scientific and Technical: New York.

Matheson, F.J. (1966): Geology of the Kajiado area. Report No. 70, Geol. Surv. Kenya.

Mathu, E.M. (1980): Polymetamorphic textures and structures of the Migwani area, Kitui. M.Sc. thesis, University of Nairobi.

Miller, J.B. (1975): Landsat images as applied to petroleum exploration in Kenya. NASA Earth Resources Survey Symposium, NASA TM X-58168 V. 1-B, p. 605-624.

Pratt, W.K. (1977): Digital Image Processing. John Wiley and Sons: New York.

Saad, M.A. (1979): The Use of Landsat Imagery and Computer Compatible Tapes for the study of Temporal Change in a portion of the Meghna River Bangladesh. Visiting International Scientists Programme (VISP) Remote Sensing Institute, SDSU - USA.

Sabins, F.F. Jr., (1978): Remote Sensing principles and interpretation. W.H. Freeman and Company: San Francisco.

Saggerson, E.P. (1957): Geology of the South Kitui area. Report No. 37, Geol. Surv. Kenya.

Saggerson, E.P. (report in publication): Geology of the Nairobi area, Report No. 98. Geol. Surv. Kenya.

Sanders, D.L. (1954): Geology of the Kitui area. Report No. 30, Geol. Surv. Kenya.

Sanders, D.L. (1963): Geology of the Voi-South Yatta area. Report No. 54, Geol. Surv. Kenya.

Schoeman, J.J. (1948): A geological reconnaissance of the area west of Kitui township. Report No. 14. Geol. Surv. Kenya.

Scott, R.M.; Webster R., and Lawrence, C.J. (1971): Land System Atlas of Western Kenya: Christchurch Hampshire England.

Short, N.M. (1982): The Landsat Tutorial Workbook. Basics of Satellite Remote Sensing. U.S. Government Printing Office: Washington.

Siegel B.S.; and Gillespie, A.R. (1980): Remote Sensing in Geology. John Wiley and Sons: New York.

ThomPson, A.O. (1964): Geology of the Kijabe area. Report No. 67, Geol. Surv. Kenya.

Walsh, J. (1963): Geology of the Ikutha area. Report No. 56, Geol. Surv. Kenya.

Remote Sensing for Transport Planning and Highway Engineering, Pilot Project in North Kenya and South Sudan; Norconsult A.S. Report for Ministry of Transport and Communication.

Ministry of Water Development, Rainfall figures.

APPENDIX 1

IMAGE PROCESSING

(a) Contrast Stretching

This is a method applied to photographically or digitally pull the range of colour hue or tone, or Digital Number (DN) values, respectively, on the image. This increases the contrast between two areas of different uniform spectral values (densities).

Photographically, this is achieved by varying the emulsion, developer or development time. Changing any one of this, changes the contrast index of each print on the image. The density range on the image is also changed.

Digitally, the process involves suppressing the lowest and highest values in an image and stretching the dynamic range of the remaining values. In this method, the pixels can also be selectively stretched using an algorithmic scale.

(b) Density Slicing

In this method, the continuous tone or colour hue of an image are converted into a series of density intervals (slices) each corresponding to a specific range of reflectance values. This is mainly done on computer and each slice can be displayed variously from other slices.

(c) Edge Enhancement

This technique is used to enhance linear features. Photographically, this involves printing an out of focus negative together with a positive transparency that is focussed. Digitally, the procedure involves spatial and directional filtering.

(d) Spatial and directional filtering

This is a mathematical process that separates the satellite scan lines (imaging lines) into their component wavelengths. The filters used to do these are designated high pass, intermediate pass or low pass depending on the spatial frequency that is transmitted through the filter.