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JAPAN INTERNATIONAL COOPERATION AGENCY

MINISTRY OF LANDS, MINERAL RESOURCES AND ENERGY
REPUBLIC OF FIJI

THE STUDY
ON
GROUNDWATER DEVELOPMENT IN NORTH VITI LEVU
IN THE REPUBLIC OF FIJI

VOLUME III

FINAL REPORT
SUPPORTING REPORT

MAY 1995

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ABBREVIATIONS

AES	Agricultural Experimental Station
APHA	American Public Health Association
AWWA	American Water Works Association
EPA	Environmental Protection Agency (United States)
FEA	Fiji Electricity Authority
FMS	Fiji Meteorological Service
FSC	Fiji Sugar Corporation
GDP	Gross Domestic Product
GNP	Gross National Product
GOF	Government of Fiji
GOJ	Government of Japan
JICA	Japan International Cooperation Agency
MFARD	Ministry of Fijian Affairs and Regional Development
MLMRE	Ministry of Lands, Mineral Resources and Energy
MOH	Ministry of Health
MRD	Mineral Resources Department
PWD	Public Works Department
WEF	Water Environment Federation (United States)
WHO	World Health Organization
EIRR	Economic Internal Rate of Return
FIRR	Financial Internal Rtae of Return
O&M	Operation and Maintenance
El	Elevation
HWL	High Water Level
LWL	Low Water Level
WL	Water Level

ABBREVIATIONS OF MEASUREMENT

Length

cm = Centimeter
m = Meter
km = Kilometer
ft = Foot
yd = Yard
mm = Milimeter
inch = Inch

Area

cm^2 = sq.cm = Square centimeter
m^2 = sq.m = Square meter
ha = Hectare
km^2 = sq.km = Square kilometer

Volume

cm^3 = cu.cm = Cubic centimeter
l = lit = liter
kl = Kiloliter
m^3 = cu.m = Cubic meter
gal. = Gallon
MCM = Million Cubic Meters

Weight

mg = Milligram
g = Gram
kg = Kilogram
ton = Metric ton
1b = Pound

Time

min = Minute
sec = Second
hr = Hour
d = Day
yr = Year

Electrical Measures

V = Volt
A = Ampere
Hz = Hertz (cycle)
W = Watt
kW = Kilowatt
MW = Megawatt

Other Measures

% = Percent
PS = Horsepower
• = Degree
' = Minute
" = Second
•C = Degree centigrade
10^3 = Thousand
10^6 = Million

Derived Measures

m^3/s = m^3/sec = Cubic meter per second
cusec = Cubic feet per second
mgd = Million gallon per day
kWh = Kilowatt hour
MWh = Megawatt hour
kVA = Kilovolt ampere
mg/l = Milligram per liter
meg/l = Milliequiralent per liter
MS/cm = Micro Siemens per centimeter
ppm = Part per million
NTU = Nephelometric turbidity unit
lpcd = Liter per capita per day

Money

F$ = Fijian Dollar
US$ = US dollar
J.Yen = Japanese Yen

APPENDIX - A

GEOLOGY

APPENDIX - A

GEOLOGY

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1. INTRODUCTION

Geological and topographic studies were carried out to obtain basic information on the natural conditions of the Study Area with regard to groundwater potential at a preliminary stage. On the basis of the obtained results from the geological and topographic studies possibly higher groundwater potential areas were selected for further studies and investigation.

Steeper areas such as areas in high mountains are considered to be lower potential areas for groundwater exploitation. On the contrary, flat plains at the foot of high mountain areas and flat and gentle plains surrounded by high mountains such as basin like land forms seem to be higher potential areas for groundwater exploitation because surface water and groundwater seems to concentrate in these flat and gentle plains. From these suppositions a selection of these flat plains at the foot of high mountainous areas and flat plains surrounded by high mountains are considered to be important for the topographic study.

Geologically groundwater potential areas are expected in areas which are under special geological conditions such as the areas underlain by thick loose materials intercalated with pervious layers and disconnected by faults, cracks, joints, etc. From this assumption, groundwater potential areas seem to be expected in areas where unconsolidated materials develop thickly as river deposits, terrace deposits, fan deposits, and so on. Reliable aquifers are expected in pervious sedimentary rocks, limestones, and volcanic lavas in general. Fractured zones developed even in the hard rocks and seem to be potential groundwater baring zones because groundwater is considered to pass through these fractured zones. From these considerations, terrace deposits, gently dipping sedimentary rock layers, and lineaments which may imply the existence of possible faults, fractured zones, and disturbed zones and so on were scrutinized in relation to their development.

In the Study Area flat plains and mountain slopes are mostly used as sugar cane fields. Forests are not predominant in the mountainous areas of the Study Area, but in general the mountainous areas are grassy lands. The runoff ratio of a river basin affects the storage coefficient of the river basin and the runoff ratio and the storage coefficient seem to be affected by the topography, geology, and vegetation of the river basin. Land use of a river basin has to be clarified when assuming of the runoff ratio and storage coefficient of the river basin.

From these considerations and assumptions, the studies on the topography, geology, and land use were carried out to obtain basic information on the natural characteristics of the Study Area. The studies were carried out by collection and analysis of existing data, interpretation of aerial photographs, and field reconnaissance. The results of the studies from this stage are summarized and shown in the land form classification map, land use classification map, and geological map.

2. INTERPRETATION OF THE AERIAL PHOTOGRAPHS AND FIELD RECONNAISSANCE

Basic studies on the topography and geology were carried out for a short period of about 1.5 months from July to August 1993. The Study Area covers a wide area of about 1,567 km^2. Taking the large size of the Study Area and the short study period into account, the studies on the topography and land use were performed by interpretation of aerial photographs of the whole Study Area and field reconnaissance in the representative sites.

The aerial photographs used for this Study were on a scale of about 1: 50,000 and they were taken in 1986, along 9 flight lines covering the study area by in a direction from the southwest to the northeast. The aerial photographs have overlapping of about 80 % among the neighboring sheets and about 60 % among the every other sheet. Since the overlapping of about 60 % is considered to be sufficient for the interpretation works of the topography and land use of the Study Area, the every other sheet of each flight line were selected for interpretation. The aerial photographs used in this Study are listed as follows:

Flight course	Photo No.	Shooting date	Sheet
3370	86,88,90,92,94,96,98,100,102,104	Jun. 1986	10
3365	50,52,54,56,58,60,62,64,66,68,70	Jun. 1986	11
3027	125,127,129,131,133,135,137,139,141,143	---	10
3365	107, 109,111,113,115,117,119	Jun. 1986	7
3027	29,31,33,35,37,39,41,43,45	---	9
3370	39,41,43,45,47,49,51,53,55,57,59	Jun. 1986	11
3370	200,202,204,206,208,210,212,214	Jun. 1986	8
3025	96,98,100,102,104,106	---	6
3025	33,35	---	2
		Total	74

On the progress of interpretation of the aerial photographs, field reconnaissance was carried out in the selected areas for confirmation of the topographic and geologic conditions and land use classification. On the basis of the field reconnaissance results, correction was carried out on the interpreted results when it was necessary.

3. LANDFORM CLASSIFICATION

3.1 General

The Study Area is mountainous in general except for the narrow coastal plains along the northern coast. In the Study Area there are four major river basins, the Ba river basin in the western part, the Nasivi river basin and the Yaqara river basin in the central part, and the Penang river basin in the eastern part. The Ba river basin is the biggest river basin in the Study Area and it occupies about 50 % of the whole Study Area. The Ba river rises in the Mt. Evans Range in the western part of the Study Area, the Naloto range is sited in the southern part, and the southern slopes of the steep mountain range of the southern Tavua in the eastern part. These mountain ranges are 800 m to 1,100 m in altitude. The highest mountain is Mt. Naqaranabuluti with an altitude of 1,127 m. The Nasivi river and Yaqara river rise in the northern slopes of the steep mountain range of the southern Tavua. The Nakauvadra river rises in the Nakauvadra range in the southern part of Rakiraki.

3.2 Landform Classification Units

Landform classification was carried out for the purpose of selection of higher groundwater potential areas. Flat plains spreading in front of mountainous areas and basins surrounded by high mountains seem to be higher groundwater potential areas. The landform classification works were carried out for the purpose of selection of the flat plains and basins. The main landform units are classified as follows, considering the characteristic features of topography in the Study Area:

- Steep mountains (higher relief area),
- Moderately steep mountains (mountainous area with a developed residual soil),
- Low hills (low relief area),
- Talus deposits including scree deposits,
- Terrace deposits,
- Alluvial plains including floodplains and valley plains,
- Tidal flats, mangrove area, and sea,
- Plateau like gently sloping highland, and
- Basin like gentle sloping lowland.

The results of the landform classification of the Study Area are shown in Figure A-3.1, Landform Classification Map. Other landform classification units such as rock outcropping cliff, cliff slope failures, landslides, volcanic necks and intrusive rocks and lineaments are also mentioned in the landform classification map.

3.2.1 Steep Mountains (Higher relief area)

Steep mountain areas in the southern and eastern marginal part of the Study Area are included into this landform unit. Rocks are expected at a shallow depth with thin overlays of weathered soil. Rock outcrops are frequently observed in the steep slopes. Landslides and slope failures are observed in this area, and talus deposits are evident in the lower parts of the slope failures and steep cliffs.

3.2.2 Moderately Steep Mountains (Mountainous area with a developed residual soil)

Gentle mountains surrounding the steep mountains or isolated relatively gentle mountain ranges are included into this unit with a minimum altitude of about 100 m. In this area moderately developed residual soil is expected in general. Landslides and slope failures are also observed in this area .

3.2.3 Low Hills (Low relief area)

Hilly and gently undulating areas with an altitude of less than 100 m are included in this group. In this area a thickly developed residual soil or weak rocks are expected. This low relief topography is predominantly developed in the Ba river basin, Nasivi river basin, Yaqara river basin, Penang river basin and coastal area. Small creeks dissect these areas, generally resulting in an undulating topography. These areas are normally cultivated as sugar cane fields.

3.2.4 Talus Deposits Including Scree Deposits

At the foot of steep cliffs and rock outcrops, relatively gently inclined slopes have developed in the steep mountain areas. These slopes are composed of angular gravel and boulders with clayey weathered soil materials derived from the steep cliffs and rock outcrops by weathering. The depth of the materials is assumed to be several meters to several 10s of meters. These materials are predominantly observed in the upstream reaches of the Yaqara river and partly in the upstream reaches of the Ba river. However, development of the areas underlain by these materials seems to be very limited in the steep mountainous areas of the Study Area.

3.2.5 Terrace Plains

There are flat plains along the major river channels with some height differences above the riverbeds, which are underlain by silty, sandy and gravely materials. These plains are terrace deposits and they have a height difference of about 10 m at the maximum point. Terrace deposits are observed along the major rivers such as the Ba river, Nasivi river and Yaqara river.

3.2.6 Alluvial Plains Including Floodplains Valley Plains

Narrow flat plains which have developed along the river channels are included in this unit, and are composed of loose clayey, sandy, and gravely materials. These materials were sedimented recently, without a large height difference, at almost the same level as the river channel. The alluvial deposits are predominantly observed along the major rivers: the Ba river, Nasivi river, Yaqara river and Nakauvadra river. Along small rivers draining directly to the northern sea there are narrow flat plains of partial alluvial deposits.

3.2.7 Tidal Flats

These are lowlands composed of silty sand materials along the northern coastal zone of the Study Area. These lowlands are submerged when the tide is high and they are classified as tidal flats.

3.2.8 Plateau Like Gently Sloping Highland

The Study Area is surrounded by high mountain ranges on the western, southern, and eastern margins. These mountains are in the stage of youth and have steep slopes or even vertical rock outcrops. Among these steep landforms are gently sloping areas, for example, plateau like gently sloping areas compared to the surrounding steeply eroded topography. Since these gently sloping areas do not seem to have been exposed to intensive erosion processes development of thick residual soil is expected in these areas.

3.2.9 Basin Like Gently Sloping Lowland

In the steep mountain area and moderately steep mountain area, rivers dissect the mountain slopes and generally create gorges and rapids. However, there are also widely opened basin like landforms along the rivers. Erosion is developed in these areas in the form of many small creeks.

3.3 Area Covered by the Landform Classification Unit

The percentage of area covered by each landform classification unit in the Study Area is summarized as follows:

Landform type	Area(km^2)	(%)
Steep mountains	718.5	45.8
Moderately steep mountains	388.7	24.8
Low hills	282.6	18.0
Alluvial deposits	48.4	3.1
Terrace deposits	35.5	2.3
Talus deposits	21.7	1.4
Plateau like gently sloping highland	46.6	3.0
Basin like lowland	25.6	1.6
Total	1567.6	100.0

4. GEOLOGY

4.1 General

For the examination of groundwater potentiality, the geological condition was confirmed at representative parts by referring to the existing data. For the examination of the basic geological condition, a geological map of the Study Area was compiled by referring to the existing geological maps prepared by MRD and available reports, such as the "Outline of the Geology of Viti Levu, 1967", "Interpretation of SLAR imagery of the main island of Fiji, 1987", and "Geology of Fiji, 1989". In the course of the compilation of a geological map similar geological units such as andesitic breccia, andesitic flows, and interbedded andesitic breccia and flows are simplified and unified as andesitic breccia and flows.

4.2 Geological Classification Units

A summarized geological map of the Study Area is shown in Fig. A -.4.1. The stratigraphy of the Study Area is summarized below.

Age	Lithology	Formation
Quaternary	Clay, silt, sand and gravel	Alluvial deposits
	Mainly silty clay and silty sand, partly gravel layers	Terrace deposits
Pliocene	Hornblende andesite lava	Vatia series
	Biotite and augite andesite Tuff, mudstone, and grits	Tavua series
	Bedded basaltic flows and breccia (Nacilau volcano) Basalt and basaltic breccia Basaltic flows (pillow lava and columnar basalt) Tuffaceous sandstone, mudstone, and tuff Basic tuff with agglomerate Chloritized trachy basaltic volcanics Augite and hornblende andesite (Karavi volcanics)	Ba series
Mio-Pliocene	Andesitic breccia and flows Intercalation of andesitic breccia and sandstone	Koroimavua series
	Sandstone and conglomerate	Suva series
Miocene	Sandstone, argillites, and conglomerate	Sigatoka series
Pliocene ?	Intrusive rocks	

The geological units mentioned in the compiled geological map are as follows from the youngest to the oldest.

4.2.1 Alluvial Deposits

The low, flat, and narrow plains along the rivers are underlain by alluvial deposits and they are composed of clay, sand and gravely materials. Alluvial deposits were observed along the Ba river, Nasivi river, Yaqara river, and Penang river, predominantly. The low and flat zone of old river channels of the Ba river, in the downstream reaches, are included in the river deposits.

4.2.2 Terrace Deposits

The flat surfaced plains along the river channels several meters above the present riverbeds are composed of terrace deposits. They are mainly composed of silty materials with a thin intercalation of sandy materials. Predominant terrace deposits were observed along the Ba river, Nasivi river, and Yaqara river. In the middle reaches of the Ba river the terrace deposits consist of mainly silty materials with rounded small gravel layers and thin shell layers, forming flat plains 5 m to 7 m above the present riverbed. However, they are 2 m to 3 m above the riverbed at the estuary of the Ba river.

4.2.3 Hornblende Andesite

Thick andesitic lavas of this group were observed on the small peninsula in the western part of Tavua. The fresh andesite is grayish and very hard but joints have developed and vertical outcrops are evident on the steep slopes.

4.2.4 Biotite and Augite Andesite

According to the Geological Map of the Tavua Area (Viti Levu, Sheet 1), these types of rocks form a circle of about 7 km in diameter in the eastern part of Vatukoula. This large circle is assumed to be a caldera.

4.2.5 Tuff, Mudstone, and Grits

These rocks surround the above biotite and augite andesite, in the form of a circle band of about 0.5 km in width. These rocks form the outer wall of the caldera.

4.2.6 Bedded Basaltic Flows and Breccia (Nacilau volcano)

The alternation of basaltic lava and breccia is included in this type. The thickness of the basaltic lava is 1 m to 2 m in general. Thin bedded tuffaceous breccia was also observed in this group.

4.2.7 Basalt And Basaltic Breccia

This group has the most common types of rocks in the Study Area and occupies more than half of the Study Area. This group consists of basaltic lavas, breccia, and tuffaceous materials with intercalating thin layers of tuffaceous sandstone and mudstone.

4.2.8 Augite and Hornblende Andesite (Karavi volcanics)

Very hard dark grayish andesites underlie the moderately steep mountains in the northwestern part of Ba. Small crystals of hornblende and augite were observed in the dark andesitic rock texture. The andesite is very hard in the fresh part but it is cracky in general. Generally residual soil has developed thickly in this part.

4.2.9 Basaltic flows (Pillow lava and columnar basalt)

Typical pillow lavas are evident in the upstream reaches of the Yaqara river. Pillow shaped lavas of 30 cm to 100 cm in diameter are piled on each other. Joints in a radial direction were frequently observed in the pillow lavas, but they are very hard in general.

4.2.10 Tuffaceous Sandstone, Mudstone and Tuff

The middle reaches of the Ba river, the southernmost part of the Study Area, and the uppermost reaches of the Ba river, are underlain by these types of rocks, predominantly. They are composed of hard sandstone of about 0.5 m in thickness with thin layers of siltstones and mudstones. The bedding planes of the rocks dip gently at around 10°. in various directions. Cracks have developed in the sandstone and they appear to be rectangular and about 50 cm in size.

4.2.11 Basic Tuff with Agglomerate

The eastern peninsula of Rakiraki is included in this type of rock group. Volcanic breccia and agglomerate were observed with weathered tuffaceous materials. Weathering of the tuffaceous rocks is developed in this part and the topography is gentle in general.

4.2.12 Chloritized Trachy Basaltic Volcanics

The rocks appear to be typically light greenish in color. The chloritized trachy basaltic rocks underlie the area of Rakiraki, surrounding a steep small mountain composed of intrusive rocks about 5 km east of Rakiraki. The chloritized trachy basaltic rocks seem to be affected by the hydrothermal process of the intrusive rocks. The rock texture is similar to the andesitic rocks and very hard in the fresh part.

4.2.13 Andesitic Breccia and Flows

This group occupies the southwestern part of the Study Area, forming steep slopes and vertical cliffs. The rocks seem to be hornblende andesite, with hornblende crystals frequently appearing in the light grayish rock texture.

4.2.14 Intercalation of Andesitic Breccia and Sandstone

The southernmost part of the Study Area is occupied by this group. Volcanic breccia has intercalated with sandstone layers in the southern part of Nanoko village. The sandstone layers seem to be affected by volcanic action and the bedding planes are intensively disturbed. The bedding planes of the sandstone layers are frequently disconnected and folded by faults and foldings.

4.2.15 Sandstone and Conglomerate

These rocks are surrounded by the above rock group and they were observed in the southernmost part of the Study Area. The rocks consist of intercalations of sandstone and shale, which form 10 cm to 20 cm thick bands. The grayish to light greenish sandstone is very hard in the fresh parts, but weathering is progressed in general. Conglomerate was only partially observed, but tuffaceous breccias were predominantly observed accompanying the alternation of sandstone and shale instead of the conglomerate.

4.2.16 Sandstone, Argillites and Conglomerate

According to the Geology of the Mbalevuto Area (Viti Levu, Sheet 5), the rocks of this group out crop in a small limited area in the western part of Navala in the upper reaches of the Ba river. This group belongs to the Miocene age and these are the oldest rocks underlying the whole Study Area. The rocks of this group appear to be in the shape of an anticline.

4.2.17 Intrusive rocks

There are two small areas of intrusive rock outcrops at about 5 km west of Rakiraki and about 3.5 km east of Vatukoula. A very steep small mountain near Rakiraki is composed of dioritic rocks.

4.3 Geological Structures

For the compilation of the geological map lineaments interpreted from aerial photographs are drawn in the map. Generally the lineaments directions are NW-SE and NE-SW. Most of the lineaments directions are NWW-SEE in the middle reaches of the Ba river, E-W, NW-SE and NE-SW in the upper reaches of the Ba river, E-W and N-S in the mountain between Ba and Tavua, NE-SW and NW-SE in the southern part of Tavua, NWW-SEE in the area of Vatukoula, NWW-SEE and NE-SW in the mountain between the Yaqara river and Rakiraki, and NWW-SEE, NE-SW and NE-SW in the Rakiraki area.

Lineaments interpreted by SLAR imagery (D.I.J.Mallick and F.Habgood, 1987) were also included in the geological map. Their remarkable directions are E-W and NE-SW in the middle reaches of the Ba river, NW-SE and NE-SW in the upper reaches of the Ba river, NW-SE and NWW-SEE in the western part of Ba, E-W, NE-SW, NWW-SEE, and NEE-SWW in the area of Vatukoula, and NWW-SEE, NEE-SWW, and NW-SE in the area of Rakiraki.

Lineaments from aerial photographs and SLAR imagery are concentrically interpreted for the middle to upper reaches of the Ba river, area surrounding Vatukoula, western part of Rakiraki, and Rakiraki area.

FIGURES

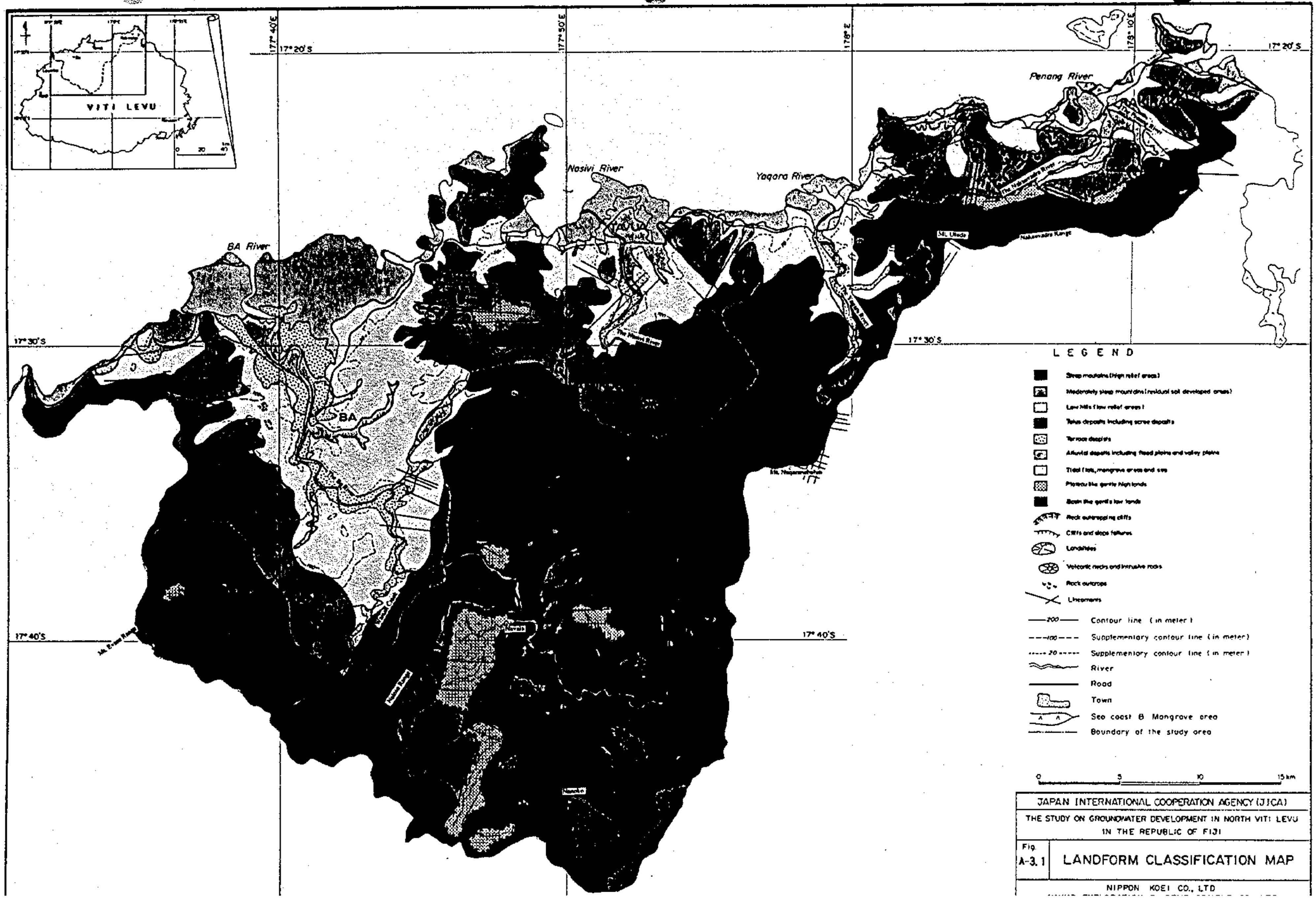

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Fig. A-3.1 LANDFORM CLASSIFICATION MAP

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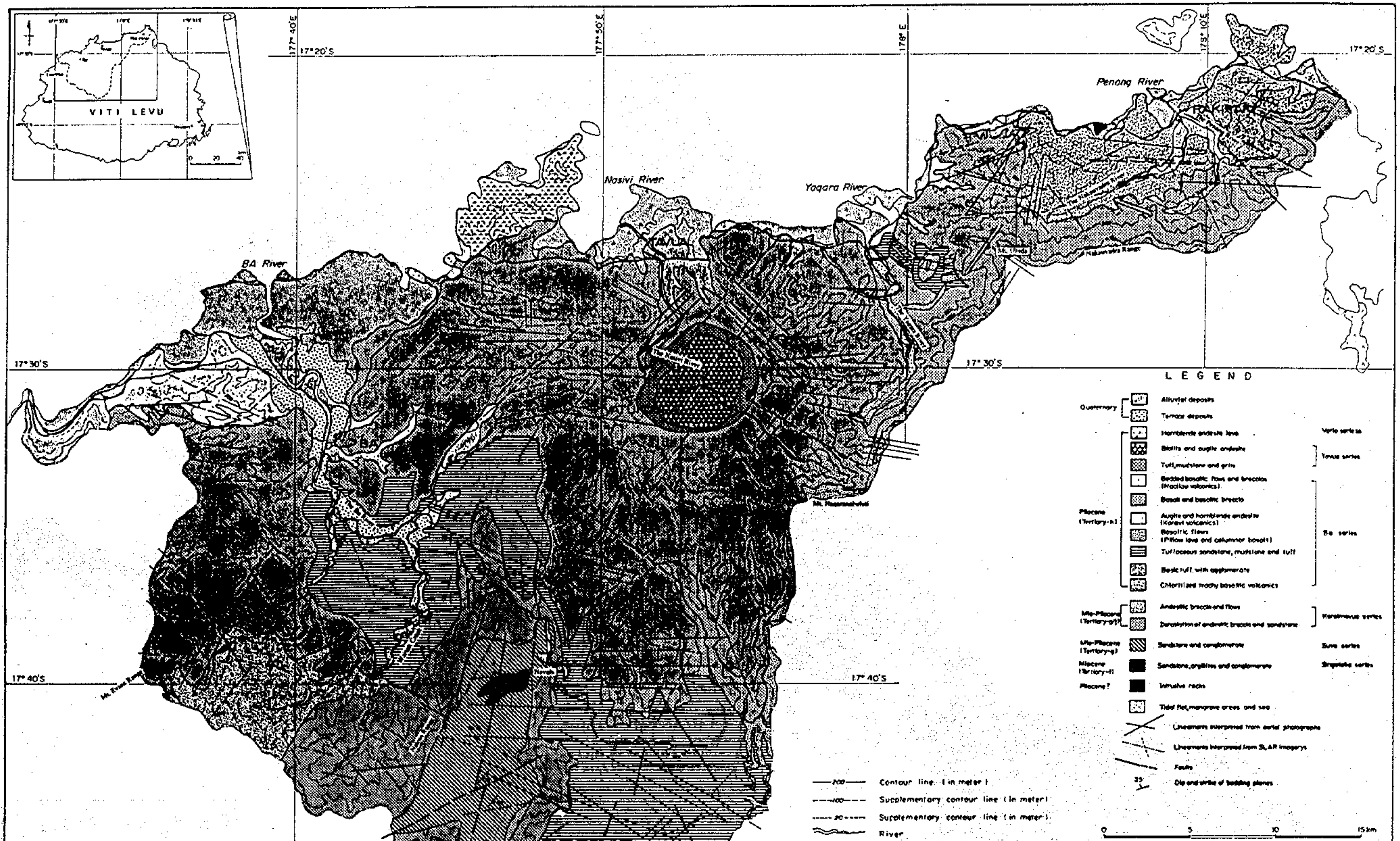

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Fig. A-4.1 GEOLOGICAL MAP

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APPENDIX - B

GEOPHYSICAL PROSPECTING

APPENDIX - B

GEOPHYSICAL PROSPECTING

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1. INTRODUCTION

Preliminary and detailed geophysical prospectings were carried out by electromagnetic sounding and electric sounding. Preliminary geophysical prospecting was conducted for confirmation of hydrogeological structures by electromagnetic sounding and electric sounding in the first field investigation from middle of June to middle of October 1994. The proposed detailed geophysical prospecting sites were selected among the preliminary geophysical prospecting sites

Detailed geophysical prospectings were carried out for selection of drilling sites in the second field investigation from middle of November 1994 to middle of January 1995.

2. PRELIMINARY GEOPHYSICAL PROSPECTING

2.1 Electromagnetic Sounding

2.1.1 General

For confirmation of the faults and fractured zones distribution, which could reveal the location of promising aquifers in the Ba volcanic rocks, electromagnetic sounding was carried out by using a Very Low Frequency (VLF) resistivity measuring system.

By this technique, the apparent resistivity of the earth is determined by magnetotelluric measurement of the radiated field from a remote radio transmitter operating for communications with submarines. The quantities measured are the horizontal components of the radial electric field (Ex) and tangential magnetic field (Hy), and the phase difference between Ex and Hy. A value for the apparent resistivity is derived from the following approximate expression :

$$\rho a = 0.2\ T\ |\ Ex\ /\ Hy\ |^2$$

where, ρa = apparent resistivity in ohm-m

T = period of the signal in seconds

Ex = electric field in mv/m

Hy = magnetic field in nanotesla

The phase angle is 45^o for homogeneous conditions, as when the depth of the layer being measured is more than one or two skin depths. When a lower layer is more resistive the phase angle will generally decrease, and it increases when a more conductive layer is present.

2.1.2 Field Works

The instrument used in this survey was a GEONICS EM16R, which determined Hy by means of an integral coil and Ex by means of two ground probes 10 m apart. The measurements were carried out by orienting the instrument so that the coil was maximally coupled to Hy (determined from an audio signal) and inserting the two ground probes in the direction indicated by the instrument orientation. After the audio signal is adjusted to be null by means of two controls, the phase angle and apparent resistivity values can be read directly from the instrument. The transmitter azimuth may be determined from the orientation of the instrument.

For this survey, the signal utilized was from VLF transmitter station NPM, Lualualei, Hawaii, at a frequency of 23.4 kHz. The transmitter azimuth was approximately north-northeast. The sites for this survey were selected on the basis of a previous study of side-looking radar (SLAR) imagery. These sites are expected to contain faults and fractured zones.

2,530 resistivity and phase angle measurements were carried out on 100 survey lines of about 500 m in length with a 20 m interval between the observation points. Fig. B-2.1 shows the location of the VLF survey lines.

2.1.3 Data Analysis

The effective depth of penetration, 'skin depth', depends on the electrical resistivity itself and slightly has on the frequency of the signal, as shown in Fig. B-2.2. If the terrain resistivity is 10 ohm-m the instrument effectively senses down to at least 10 m and if the resistivity is 100 ohm-m the penetration depth is 33 m.

The apparent resistivity and phase angle profiles obtained from the 100 survey lines are shown in Fig. B-2.3.

The most obvious feature in Fig. B-2.3 is the low resistivity in general. Most of the apparent resistivity values are less than 100 ohm-m, and more than half of them are less than 30 ohm-m. This indicates that the surface is composed of highly weathered material. The phase angle values mostly vary between 15° and 60°. Many low resistivity anomalies may be found, but most of them are likely to be due to weathering of the surface because of their phase angles of less than 45°, indicating that the lower part is more resistive than the surface.

Water within the faults and fractures in the volcanics will produce distinct low resistivity anomalies against the solid rock.

Some promising areas with faults and fractured zones can be found where distinct low resistivity anomalies and phase angles of more than 45° exist, indicating that the lower layer is more conductive than the surface. They are identified by hatching in their profiles shown in Fig. B-2.3 and their locations are shown in Fig. B-2.9. Fairly significant anomalies are found in line 2, 12, 31, 32, 35, 41, and 42.

For example, the apparent resistivity is 10 ohm-m and the phase angle is 50° in the center of line 12. Two-layer interpretation then gives a lower layer resistivity of 8.2 ohm-m and an upper layer thickness of 1.1 m, when the resistivity of the upper layer is assumed as 60 ohm-m derived from an adjacent reading where the earth is not two-layered as indicated by a phase angle of 45°.

It is proposed that more detailed VLF survey should be conducted in the following areas with a 10 m sampling interval to determine the detailed distribution of faults and fractured zones and to decide the location of drilling sites.

1) Around line 32 in Vutuni, Ba
2) Around line 12 in Qara, Tavua
3) Around line 35 in Waikowa, Tavua
4) Around line 2 in Tagitagi, Ba
5) Around line 41 in Vatukoula, Tavua

2.2 Electric Sounding

2.2.1 General

For identifying subsurface geological structures and for selection of drilling sites in the areas underlain by alluvial deposits and at the foot of the volcanoes, electric sounding was carried out by vertical electric sounding (VES) with the Wenner electrode array.

Electric sounding is intended to detect changes in the resistivity of the earth with depth at one location (assuming horizontal layering). The quantities measured were electric current (I) sent into the ground through two current electrodes and voltage difference (V) between two potential electrodes. In the Wenner array which is one of the electrode arrangement in resistivity prospecting, four electrodes were spaced equally in-line. The apparent resistivity (ρa) is given by the following equation for the Wenner array :

$$\rho a = 2\pi aV / I$$

where, a = electrode spacing in meters
V = voltage difference in volts
I = electric current in amperes

2.2.2 Field Works

The instruments used in this survey were a resistivity meter OYO McOHM model-2115, a power booster OYO McOHM model-2917, and a 12 V car battery for the power supply. The current and voltage values were read from the digital display of the resistivity meter.

With vertical electric sounding the electrode spacing is increased to determine the resistivity at successively greater depths at a given surface location. In this survey measurements were carried out using 19 different electrode spacings from 2 m to 150 m at 134 survey points. The locations of the 134 VES points are shown in Fig. B-2.1.

2.2.3 Data Analysis

Fig. B-2.4 shows the distribution of apparent resistivity at an electrode spacing of 50 m. Low resistivities of less than 30 ohm-m were found in areas along the Ba river, in the east of Tavua, between Rabulu and Yaqara, and in the north of Rakiraki. High resistivities of more than 50 ohm-m were found in the east of Ba, in the west of Tavua, and in the south of Rakiraki.

The results of the interpretation of all the resistivity soundings are presented in Fig. B-2.5. This interpretation was carried out by using the one dimensional inversion method based on curve matching and modeling and using a personal computer (NEC-9801N). In Fig. B-2.5 the solid line curve represents the theoretical apparent resistivity value of the final model, and an 'O' indicates the measured value.

A first appraisal of an area's hydrogeology can often be carried out by merely looking at the shape of the field curves and the range of apparent resistivity values. The comparison of curves leads to the recognition in type curves and enables the curves to be divided into groups. 134 VES curves of this area were classified into 5 groups, A through E. Typical curves of each group are shown in Fig. B-2.6.

Curves of type A show a gradual decrease in the apparent resistivity with depth. The most common type of curve in this area is type B. These curves show on increase in the resistivity with depth. With curves of type C, the resistivity falls in the center of the curves, while type D curves rise in the center, indicating that the resistivity basement lies beyond the penetration depth of the soundings. With curves of type E, the 4 or 5 layer model, the resistivity slopes upward and downward alternately.

Eleven soundings were located close to the successful bore holes of MRD and PWD, shown in Fig. B-.2.1. Nine sounding curves (No.2, 5, 56, 57, 64, 70, 71, 76, and 110) belong in type E, and 2 curves (No.24 and 66) belong in type D. Survey points whose curves belong in type D or type E are marked in Fig. B-2.9.

When compared with the well data shown in Fig. B-2.7, the main aquifer is probably in the low resistivity zone beneath or between the high resistivity layers.

34 sections of the resistivity structure derived from the interpretations of 134 soundings are shown in Fig. B-2.8. A resistivity boundary of 30 ohm-m can be roughly divided into low and high resistivity zones, which may be subdivided into two zones by boundaries of 10 ohm-m and 100 ohm-m, respectively.

The low resistivity zone will correspond to the weathered volcanic and sedimentary material or fractured zone, and the high resistivity zone will reflect fresh volcanic rocks. The very low resistivities of less than 10 ohm-m possibly point to a higher clay content or a higher groundwater salinity.

Consequently, the aquifer zone in this area is likely to be characterized by resistivities of less than about 30 ohm-m beneath or between the high resistivity zones. The areas with the above mentioned resistivity structures are shown in Fig. B-2.9.

It is proposed that more detailed electric sounding should be carried out in the following areas with about a 200 m interval between survey points to identify detailed subsurface resistivity structures and select drilling sites and depths:

1) Around No.15 in the west of Ba
2) Around No.23 and No.39 in the south of Ba
3) Around No.45 in the east of Ba
4) Around No.58 and No.63 in the north of Ba
5) Around No.74, No.75 and No.78 in the west of Tavua
6) Along line ET-7 on Rabulu road in the east of Tavua
7) Around No.112 in Yaqara
8) Around No.129 and No.134 in the south of Rakiraki

3. DETAILED GEOPHYSICAL PROSPECTING

3.1 Electromagnetic Sounding

Detailed electromagnetic sounding was carried out at Vutuni, Qara, and Waikowa, as shown in Table B-3.1. in order to detect fissure zones which were said to exist by the previous geological and geophysical studies. Resistivity and the phase angle were measured at 180 spots along the 14 survey lines of intervals of 10-20 meters, using an apparatus called GEONICS EM16R which receives VLF of 23.4 Hz from NPM, Lualualei, Hawaii. The profiles of the resistivity and phase angle obtained along the 14 survey lines are shown in Fig. B-3.2.

3.2 Electric Sounding

Detailed vertical electric sounding (VES) was carried out with Wenner's electrode array at 77 spots in 14 areas, as shown in Table 2.1.1, prospecting to a maximum depth of 150 meters using an apparatus called OYO McOHM model-2115 and a power booster called OYO McOHM model-2917. The results obtained from the measurement and analyzed resistivity columns are shown in Figs. B-3.3 and B-3.4, respectively.

3.3 Selection of Test Well Sites

Test well sites were initially selected in the study period of the first Phase based on the results of the field geological investigation, geophysical prospecting, and social situation. It is found that low resistivity anomaly in basalt masses indicates that fault share zones or fissures may occur, thus, permitting groundwater to flow. The test well sites including alternative sites were finally determined by the analysis of detailed soundings which indicated that low resistivity anomalies exist, as shown in Fig. B-3.1.

TABLES

Table B-3.1 GEOPHYSCIAL PROSPECTINGS AREAS OF THE DETAILED SURVEY

Category	Area No.	Survey Area	Method	Test well No.
Proposed sites				
	No.1	Vutuni	VLF	TW001
	No.2	Yalalevu	VES	TW002
	No.3	Nukuloa	VES	TW003
	No.4	Varandoli	VES	TW004
	No.5	Veisaru	VES	TW005
	No.6	Koronubu	VES	TW006, TW006A
	No.7	Qara	VES	
	No.8	Kukunirewa	VES	TW008
	No.9	Drumasi	VES	TW009
	No.10	Rabulu	VES	TW010
	No.11	Wairuku	VES	TW011
Tentative proposed sites				
	Alt-1	Vaileka	VES	TW012
	Alt-2	Yasiyasi	VES	
	Alt-3	Yaladro	VES	
	Alt-4	Balata	VES	
	Alt-5	Vatia	VES	
	Alt-6	Waikowa	VLF	