DEMOCRATIC REPUBLIC OF MADAGASCAR
MINISTRY OF INDUSTRIES, ENERGY AND MINES

THE DEVELOPMENT STUDY
IN
THE SOUTH-WESTERN REGION
OF
THE DEMOCRATIC REPUBLIC OF MADAGASCAR

VOLUME 3
SUPPORTING REPORT (1)

JAPAN INTERNATIONAL COOPERATION AGENCY

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1. HYDROGEOLOGICAL MAP

1. HYDROGEOLOGICAL MAP

1.1 Outline of hydrogeological map

The hydrogeological map of "Toliara Region" drawn on a scale of 1:250,000 indicating the hydrogeological condition of a total area of 31,259km^2 covering the entire prefectures of Morombe, Ankazoabo, Toliara, and Sakaraha and part of the Beroroha Prefecture, in Toliara Province, has been prepared as a result of investigations (hereinafter called this investigation) for the groundwater resource development project (1989-1991) carried out in the southwestern region of Madagascar by the Japanese Government in response to the request of the Government of the Democratic Republic of Madagascar.

The above-mentioned region is situated in a tropical subarid climate zone, and the people living in the region always suffer from the shortage of water supply and sanitary problem, because they obtain most of the water they need from surface flowing water sources and shallow wells. Therefore, development of groundwater resources is an urgent necessity of the region, and this hydrogeological map has been prepared with the purpose of providing the project with fundamental data needed for the formulation of a concrete development plan.

(1) Methodology

This hydrogeological map was prepared in the following way by taking into account particular conditions of the region and the restricted time which was available for this investigation.

1) The entire area of the region is covered by topographical maps drawn on a scale of 1:100,000 in the 1950's, but the maps have not been updated to reflect various changes in roads and geographical features which took place after the publication. Therefore, 1:250,000-scale topographical maps were prepared by enlarging a published topographical map "Carte de Madagasikara 9 Toliara" drawn on a scale of 1:500,000 and used as a basic map for this investigation.

2) Geological maps drawn on scales of 1:200,000 and 1:500,000 were already available, indicating such geologi-

cal information as strata, rocks, tectonic lines, etc. Since the geological maps were confirmed to be highly reliable as a result of field reconnaissance surveys, classification of the facies in the region was made based on the information obtained from the above-mentioned geological maps and published references, as well as interpretation results of satellite images and data obtained from the field reconnaissance surveys.

3) Regarding the subsurface geology, available information was limited to geologic columnar sections of 10 petroleum exploration wells (drilled to the depth of 1,200-4,000m) and 15 groundwater exploration boreholes (drilled mostly in the western limestone area to the depth of less than 200m). Therefore, the subsurface facies distribution shown in the cross sections was estimated from a facies map drawn in the above-mentioned way and the results obtained from 26 test wells (2,096m in total drilled depth) and electrical prospecting (at 249 points of 82 locations with interpreted depth of 50-300m) made as part of this investigation.

4) No data were available regarding the level and flow condition of groundwater except those obtained from the above-mentioned test wells, nor did exist any well at which the water level had been measured continuously. Therefore, the level and flow condition of groundwater were estimated based on the results obtained from simultaneous observations of water level performed 2 or 3 times at about 70 wells during the course of this investigation, and simulation results of the flow state of groundwater obtained from a two-dimensional model of cross section prepared by considering the topography only.

(2) Procedure and Data

Fig. 1 shows the preparation procedure of this hydrogeological map, and Tables 1 to 3 give lists of main existing materials referred to for preparing the map.

(3) Composition and Content

This hydrogeological map of "Toliara Region" is composed of two B1-size sheets (Sheet 1 and Sheet 2). On the front side of Sheets 1 and 2, hydrogeological maps drawn on a scale of

1:250,000, index maps, and legends are given and, on the back side of Sheet 1, regional geological cross sections (drawn on a horizontal scale of 1:100,000 and vertical scale of 1:10,000) of principal areas are shown. Hydrogeological cross sections at the locations where test wells were drilled and electrical prospecting was carried out are shown on the back or Sheet 2.

Contents of the information (legend) shown in the hydrogeological map are summarized below.

1) Facies classification

In this hydrogeological map, ordinary stratigraphic classification was not adopted, but facies classification was used indicating the hydrogeological characteristics of strata. The method used for classifying strata was not the same over the entire region, but the most suitable method was adopted for each district depending upon the accuracy of the investigations and the kind, occurrence, physical characteristics, etc., of the strata and rocks found in each district. A total of 12 facies was classified over the region.

2) Geological age

Since most of the strata and rocks underlying the region were considered to be of Jurassic period or younger, the Jurassic system and younger strata and rocks were divided into "Systems", and each system was further divided into an upper, middle, and lower subsystems. However, since the Palaeogene system was composed mainly of Eocene series, the series was subdivided.

3) Structural element

Since the strata found in the Study Area generally lie with gentle dips of several degrees, strike measurement was made as accurately as possible so as to prevent a large error in strike. Tectonic lines were divided into unconcealed faults shown in the geological maps and lineament identified from satellite images and aerial photographs.

4) Potential for groundwater development

In order to make the hydrogeological map practically useful, potential for groundwater development must be indicated in the map. While various methods have been proposed for evaluating the potential, this map relatively divides the potential into 7 categories. These 7 categories resulted from the combination of the yield of main aquifers, which is divided into 3 categories, and distributed depth of the aquifers, which is also divided into 3 categories.

5) Occurrence of groundwater

It is very hard to confirm the flow direction of groundwater unless a fixed number of water level measuring points are available. In the area along National Highway 9, there existed many water wells and the level and flow direction of unconfined groundwater could be known from the results of simultaneous observations made at such wells. However, those of confined groundwater could not be surveyed accurately due to the shortage of deep wells. In other areas, the flow direction of groundwater had to be estimated from the geographical features and geological structures, because water level could not be surveyed due to insufficient number of available wells. Springs which were considered to be outcrops of groundwater were mainly identified from the geological maps.

6) Occurrence of surface flowing water

Since the Study Area belongs to a semiarid climate zone, states of rivers and lakes extensively vary between the rainy and dry seasons. A perennial river (lake) was differentiated from a seasonal river (lake) in accordance with the map "Carte De Madagasikara 9 Toliara". In addition, marshes and paddy fields, suggesting the presence of stagnation of surface flowing water or springs, were mainly copied from topographical maps drawn on a scale of 1:100,000.

7) Water utilizing facility

The water utilizing facility used in this report means the wells which are used by the local people for getting water. Wells could be classified on the basis of their structure

and pumping capacity, but, in this hydrogeological map, they were classified on the basis of their depths, so as to know the approximate depths of the aquifers from which the local people obtained water.

8) Weather and hydrological stations

While a total of 7 weather stations(2 of which were precipitation stations) existed in the Study Area, 3 automatic rain gauges and 5 automatic water gauges (for measuring water level) were newly installed. In addition, since no river flow monitoring station exists in the region, the flow rate values obtained from 3 points, and the flow records from existing references are indicated in this report as reference values.

9) Others

Villages marked in the map are limited to those shown in the map "Carte de Madagasikara 9 Toliara" as having populations of 500 or more. However, villages which were subject of actual condition surveys are marked on the map even when their populations are less than 500. The village numbers marked on the map are tentatively given to meet the convenience of the actual condition surveys.

The classifying method of strata and age of each stratum underlying the Study Area are somewhat different by materials. Table 4 gives the comparison of the classification and ages between each material in addition to the stratigraphic succession adopted in this report.

1.2 Local Hydrogeological Map

Attached in nect page shows the sample of local hydrogeological map scaled 1:100,000.

Table-1 Exisiting geological maps

Title	Map No.	Scale	Year published
MORONDAVA,AMBOHIBE,MANJA	503,522,523	1/200,000	1952
MOROMBE-BEFANDRIANA	542,543	do	1952
ANKAZOABO-BEROROHA	544,545	do	1956
MANOMBO-MANERA	562,563	do	1956
SAKARAHA-RANOHIRA	564,565	do	1956
TULEAR-BENENITRA	582,583	do	1956
SAKOA-BENENITRA	584,585	do	1956
MADAGASCAR	Feuille du Sud	1/1,000,000	1965
MORONDAVA	No.6	1/500,000	1969
AMPANIHY	No.8	do	1970

Table-2 Exisiting geological literatures

Title	Author or Editor	Year published
GEOLOGIE DE MADAGASCAR	Henri BASAIRE	1972
ETUDE DES RESSOUCES EN EAUX SOUTERRAINES A MADAGASCAR	L.LESSARD	1968
LES GRANDS TRAITS DE L'HYDRAULIQUE A MADAGASCAR	Ch.A.DOMERGUE	1971

Table-3 Satellite images and aerophotoes used in the Study

Source	Sale	Date
LANDSAT-1 MSS Panchromatic image	1:500,000	1973
LANDSAT-4 TM (Digital data)		Jan.17,1985
SPOT-1 Panchromatic image	1:100,000	1986,1988
Panchromatic Aerophotoes	1:40,000-1:45,000	1949

Table Comparison between Stratigraphic Classifications

Geological Time \ Geological Map				1/1,000,000 Madagascar (1965)	1/500,000 MORONDAVA (1969)	1/500,000 AMPANIHY (1970)	1/250,000 This Map (1991)	
Quaternary	Alluvium			a, d	a, d^1	a, d^1	a	d
Quaternary	Pleistocene			ac, d^1	ac, d^a	ac,cc,d^2,d^3	f	d
Tertiary	Neogene	Pliocene		n*	P*	N*	N	N*
Tertiary	Neogene	Miocene		m	m	m		
Tertiary	Paleogene	Oligocene		e				
Tertiary	Paleogene	Eocene	Ludian	e	e^2	e^3	Em+u	
Tertiary	Paleogene	Eocene	Ledian	e	e^2	e^3	Em+u	
Tertiary	Paleogene	Eocene	Lutetian	e	e^1	e^2	El	
Tertiary	Paleogene	Eocene	Ypresian	e	e^1	e^2	El	
Tertiary	Paleogene	Paleocene				e^1		
Mesozoic	Cretaceous	Upper	Maestrichtian	C^2	C^{9-8}	C^{9-8}	Cu	
Mesozoic	Cretaceous	Upper	Campanian	C^2	C^{9-8}	C^{9-8}	Cu	
Mesozoic	Cretaceous	Upper	Santonian	C^2	C^7	C^{7-3}	Cu	
Mesozoic	Cretaceous	Upper	Coniacian	C^2	C^7	C^{7-3}	Cu	
Mesozoic	Cretaceous	Upper	Turonian	C^1	C^{6-3}	C^{7-3}	Cm+ℓ	
Mesozoic	Cretaceous	Upper	Cenomanian	C^1	C^{6-3}	C^{7-3}	Cm+ℓ	
Mesozoic	Cretaceous	Lower	Albian	C^1	C^{6-3}	C^{7-3}	Cm+ℓ	
Mesozoic	Cretaceous	Lower	Aptian	C^1	C^1		Cm+ℓ	
Mesozoic	Cretaceous	Lower	Neocomian	C^1	Cv			
Mesozoic	Jurassic	Upper	Tithonian	J^3	J^{8-5}	J^8	Ju	
Mesozoic	Jurassic	Upper	Kimmeridgian	J^3	J^{8-5}	J^8	Ju	
Mesozoic	Jurassic	Upper	Oxfordian	J^3	J^{4-2}	J^4	Ju	$I_{III}^{*\Delta}$
Mesozoic	Jurassic	Middle	Callovian	J^2	J^1	J_1^1	Jm	$I_{III}^{*\Delta}$
Mesozoic	Jurassic	Middle	Bathonian	J^2	J_{I-II} / J_{III-IV}	J_{I-IV} / I_{III}^*	Jm	$I_{III}^{*\Delta}$
Mesozoic	Jurassic	Middle	Bajocian	J^2	J_{III-IV} / I_{III}	I_{III}^*	Jm	$I_{III}^{*\Delta}$
Mesozoic	Jurassic	Lower	Aalenian	(J^1)	I_{II}	I_{II}		I_{II}^*
Mesozoic	Jurassic	Lower	Lias	(J^1)	I_{II} / I_I	I_{II} / I_I		I_{II}^* / I_I^*
Mesozoic	Triassic			K^2	(Sakamena G.) K^6~K^4	(Sakamena G.) K^4, K^3	PJu	
Paleozoic	Permian			K^2	(Sakamena G.) K^6~K^4	(Sakamena G.) K^4, K^3	PJu	
Paleozoic	Carbaniferous			K^{1*}	(Sakoa G.) K^1~K^3	(Sakoa G.) K^2, K^1	$PJ_ℓ$	
Igneous rock (Basalt)	Post Eocene			$β^2$	$β^3$	$β^3$	$β^2$	
Igneous rock (Basalt)	Pre Eocene			$β^1$	$β^1$, $β^2$	$β^1$, $β^2$	$β^1$	

(Isalo Group)

* Continental facies sediments
△ Mixed facies sediments

Table-5 Major areas and the villages belonged

Area name	Village number
A. Mangoky Delta	1,2,3,4,5,6,7,8,11,12,13,14,15,16,17,18, 30,31
B. Lake Ihotry Basin	21,22,23,24,25,26,27,28,29
C. Manombo Basin	52,53,54,55,56,57,58,59,60,61,62,63,64,65,66, 67,68,69,76,101
D. Fiherenana Delta	74,75,
E. Belomotra-Vineta Plateau	70,71,72,73,77,78,79,80,81,93,94,95,
F. Fiherenana Basin	82,83,84,85,86,88,89, 90,91,92
G. Sakondry Basin	98,99
H. Taheza Basin	95,96,97,100
I. Sakanavaka Basin	33,34,35,36,37,38,39,40,41
J. Isahena Basin	42,43,44,45,46,47,48,49,50
K. ETC.	32,49,51

* Underlined number are the villages on which the electric prspecting and/or test drilling were carried out.

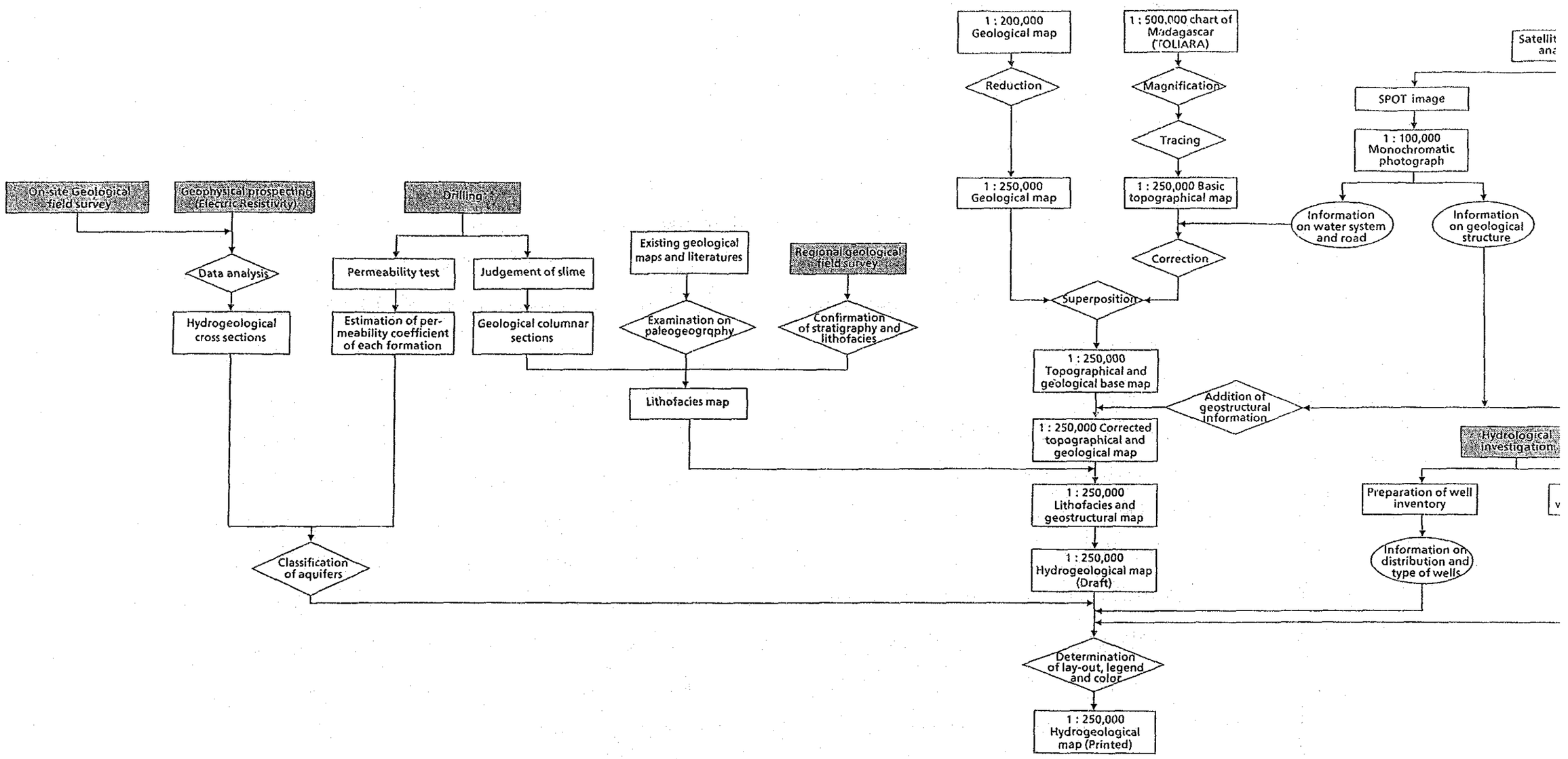

On-site Geological field survey
Geophysical prospecting (Electric Resistivity)
Drilling
Data analysis
Hydrogeological cross sections
Permeability test
Judgement of slime
Estimation of permeability coefficient of each formation
Geological columnar sections
Existing geological maps and literatures
Examination on paleogeogrqphy
Regional geological field survey
Confirmation of stratigraphy and lithofacies
Lithofacies map
Classification of aquifers
1 : 200,000 Geological map
Reduction
1 : 250,000 Geological map
1 : 500,000 chart of Madagascar (TOLIARA)
Magnification
Tracing
1 : 250,000 Basic topographical map
Correction
Superposition
1 : 250,000 Topographical and geological base map
Addition of geostructural information
1 : 250,000 Corrected topographical and geological map
1 : 250,000 Lithofacies and geostructural map
1 : 250,000 Hydrogeological map (Draft)
Determination of lay-out, legend and color
1 : 250,000 Hydrogeological map (Printed)
Satellit
ana
SPOT image
1 : 100,000 Monochromatic photograph
Information on water system and road
Information on geological structure
Hydrological investigation
Preparation of well inventory
Information on distribution and type of wells
v

Fig. 1 Make ou

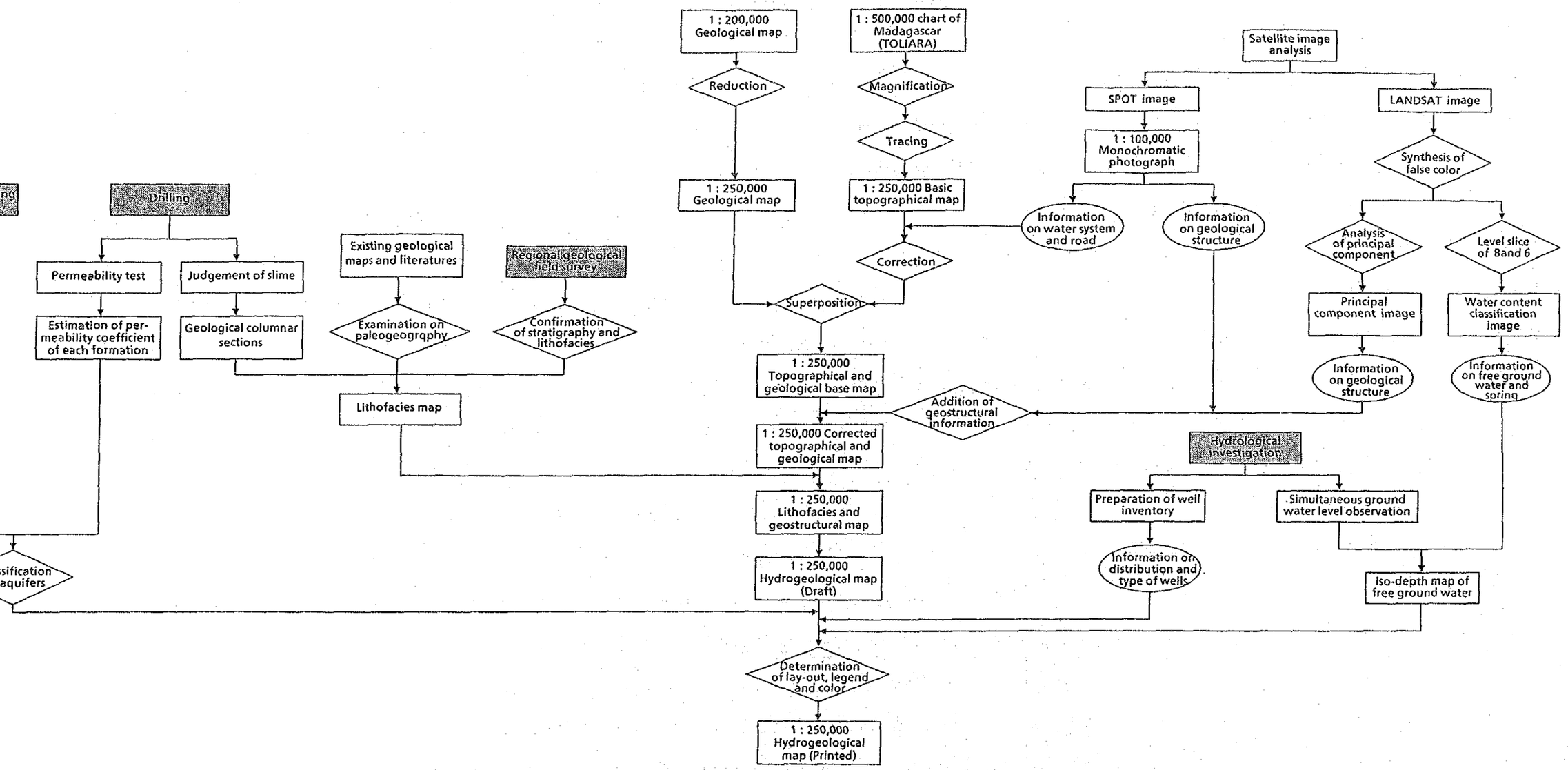


Fig. 1 Make out process of the hydrogeological map

LEGEND OF THE HYDROGEOLOGICAL MAP

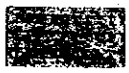
Lithofacies

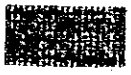

Alluvium


Dune sand


Alluvial fan deposits

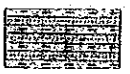

Basalt(Sheet and volcanic neck)


Alternation of limestone and marl


Soft and porous limestone

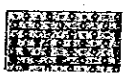

Compact but fissured limestone


Marl


Fine to medium grained marine sandstone with calcareous or marly sediments


Calcareous sandstone with continental sandstone


Continental sandstone with siltstone

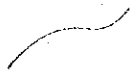

Medium to coarse grained continental sandstone


Basement complex (pre-Jurassic)


Strike and dip


Fault


Lineament


Litho-stratigraphic boundary


Lake


Marsh or swampy area


Paddy field


River

HYDROGEOLOGICAL MAP

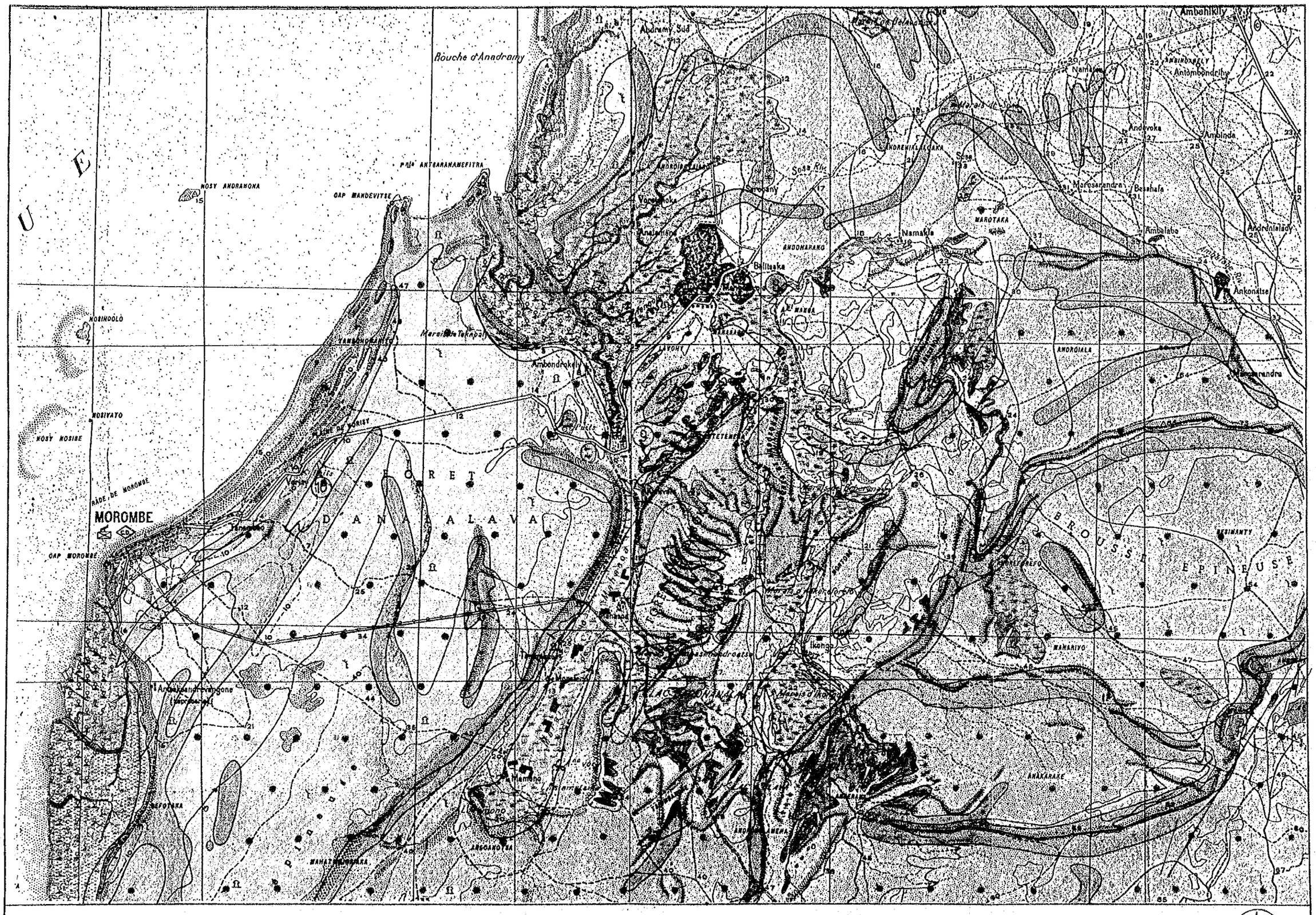
(Sheet E-57 ; 1/100,000)

0 50 km

HYDROGEOLOGICAL MAP

(Sheet C-53 ; 1/100,000)

0 50 km



HYDROGEOLOGICAL MAP

(Sheet C-54 ; 1/100,000)

0 50 km