with groundwater levels varying from 5 to 25m. The deepest borehole exists in Andranohinaly village (219m); this borehole has also the lowest groundwater level (207m). Table 3.5.1 also shows that the depth of most dug wells is less than 10m.

Since the actual positions of screens in all boreholes were unknown due to lack of drilling records, the locations of the aquifers could not be determined.

3.5.2 Groundwater Levelling

(1) Simulataneous Groundwater Levelling

In order to analyze the groundwater flow and direction, water level in many existing wells was measured simultaneously.

Table 3.5.1 shows the groundwater levels (from the ground surface) in the wells inspected. These groundwater levels resulted from the simultaneous groundwater leveling at the onset of the rainy season in October and November 1989, during the rainy season in February and March 1990 and the dry season in June and July 1990. Principal results of these three measurements is shown in Fig 3.5.1.

From the onset and towards the end of the rainy season, the groundwater levels in most wells rose by one to two meters. Groundwater level fluctuation was more than three meters in some wells. The same was true at Ambatolily where an automatic water level recorder was installed. These results suggest that these wells are tapping unconfined aquifers in which pronounced fluctuations of groundwater levels occur as a quick response to rainfall.

In Miary, there are four deep wells which supply water to Toliara area and are operated by JIRAMA . The groundwater level in the observation well was measured at 22.60m when pumping was going on in November 1989, and at 22.40m when no pump was operating in March 1990. The aquifer being tapped is believed to be of fractured limestone or calcareous sandstone. In Andranomena, which is adjacent to Miary, the groundwater level from the same aquifer went up by 2.33m from 6.73m below ground level.

In some dug wells located in Bereketa, Befanamy and Berobotsy, the groundwater level did not change. In areas like Tranokaky and Tsianisiha, the withdrawal rate of groundwater by village people during the day may exceed the rate at which groundwater inflows from the surrounding areas and, as a result, water table falls. During the evening, when the people do not use the wells, the withdrawal rate is nil, and it will be exceeded by groundwater inflow, so that the water table level will recover.

(2) Continuous Groundwater Levelling

In order to analyze groundwater behavior through the year, automatic water level recorders were installed at two existing and three test wells in the following villages.

Village	Well depth	Date installed	Remarks
- Soahazo	34.0	July 1990	(test well)
- Ankaraobato	75.5	July 1990	(test well)
- Anbatolily	12.0	Dec 1989	(existing well)
- Maninday	73.5	July 1990	(test well)
- Sakaraha	16.8	Dec 1989	(existing well)

Fig. 3.5.2(1) shows the monitoring results of Anbatolily and Sakaraha, while Fig. 3.5.2(2) shows those of Soahazo, Ankaraobato and Maninday.

The recorder at Sakaraha showed a rise of only 10cm from the 10.35m (below ground level) measured in December 1989. With a very slow response to rainfall, this well might be drawing water from a confined aquifer.

The groundwater level at Maninday was 16.06m below ground level on August 6, 1990. This level increased gradually to its highest level of 15.60m on September 21. From the peak, water level continuously decreased down 18.0m below ground surface at the end of January, remaining at this level until the middle of March. On the other hand, monthly rain fall from December to February was recorded as 39mm, 157mm, 158mm, 230mm. From this result, it can be considered that the aquifer of Maninday is mostly influenced by regional groundwater flow system, with little response to rainfall in surrounding areas.

The recorder at Anbatolily showed the groundwater level condition from December 1989 up to the present. Unfortunately, the records from the mid-January to mid-February period were not available because of poor equipment maintenance resulting from terrible road conditions, which made the village inaccessible. However, an outline of level movement can be read from this figure. The level started from 3.20m below ground surface and peaked at 2.7m during the rainy season. From this peak, the level gradually decreased except for some small recovery in the first week of May. Monthly rainfalls at Ankaraobato (the nearest rainfall station from Anbatolily) were 157mm in December 1989, and 258mm, 52mm, 8mm and 31mm in January, February, March and April 1990, respectively.

The groundwater level records at Soahazo and at Ankaraobato are available since August 1990 to March 1991. The groundwater level movement was different in the two villages during the July-September period. The level at Soahazo decreased from 5.66m to 6.09m, while the level at Ankaraobato increased from 4.00m to 3.88m. The rainfall during this period was 23mm in July, 0mm in August and 4mm in September.

From these results, it is necessary to consider recharge sources other than rainfall for the wells at Ankaraobato (and may be at Anbatolily too). Possible sources could be the swamp and paddy fields fed by the Amboboka springs.

The general condition of the Amboboka springs is discussed in Subsection 3.4.2. The outflow from these five springs is stored first in the swamp and then diverted to the surrounding paddy fields. The diversion through earth canals, however, does not look efficient; this can be advantageous, i.e., some amount of water can recharge the groundwater, thereby increasing groundwater level around this area.

During a broad conclusion from the groundwater fluctuation, the aquifers in these 3 stations, Soahazo, Ankaraobato, and Anbatolily are estimated to be of the unconfined type because of their quick response to rainfall.

Table 3.5.1 Results of Well Inventory (1)

*** Legend ***
(1) Well type: Borehole -- 1, Protected shallow well -- 2, Dug well -- 3
(2) Completed Year of the Well Construction
(3) Existing Condition: working----1, not working but measurable---2, not working---3
(4) Well depth (m)
(5) Static ground water level (below ground level in m)

WELL CODE	VILLAGE	TYPE (1)	DATE (2)	COND. (3)	DEPTH (4)	W/L (5)	WATER LEVEL NOV-DEC	FEB-MAR	JUN-JUL
1701	MIARY4 F2	1	1988	1	41	20.55	20.1	-	20.67
1702	MIARY F3	1	1979	1	41.7	18.45	-	-	-
1703	MIARY F4	1	1980	1	65.62	4.02	-	-	-
1704	MIARY OB.	1	-	1	-	-	22.6	22.4	22.4
1705	ANDRANOMENA1	1	-	1	60.6	6.53	10.62	4.2	-
1706	ANDRANOMENA2	1	1986	1	60	19.33	-	-	-
1801	MIARY E1	2	-	2	-	-	2.15	-0.28	3.14
1802	MIARY P1	2	-	2	-	-	4.42	2.26	4.32
1803	MIARY P2	2	-	2	-	-			4.22
1804	BEFANAMY	2	-	1	8.56	-	5.9	6.05	5.5
1805	ANDROVAKELY	2	-	1	-	-	4.35	4.4	3.9
1806	MONTOMBE	2	-	1	3.6	-	2.3	1.12	1.23
1807	AIRPORT	2	-	1	8.04	-	6	5.86	5.71
2701	ANKILIMALINIKA1	1	-	3	25	15	-	-	-
2702	BENETSE1	1	-	3	22.58	14.9	-	-	-
2703	SARIRIAKA1	1	-	2	26	16.5	-	-	-
2704	TSIANISIHA1	1	-	3	15.5	9	-	-	-
2705	TSIANISIHA2	1	-	3	25	18.5	-	-	-
2706	TSIHOSY	1	-	2	20.8	17	-	-	-
2707	AMBATOLILY	1	1966	2	12	2.5	3.45	2.7	3.82
2708	AMBATOLILY2	1	1965	3	-	-	-	-	-
2709	AMBALAVENOKA	1	-	3	-	-	-	-	-

Table 3.5.1 Results of Well Inventory (2)

NUMBER	VILLAGE	TYPE (1)	DATE (2)	COND. (3)	DEPTH (4)	W/L (5)	WATER LEVEL NOV-DEC	WATER LEVEL FEB-MAR	WATER LEVEL JUN-JUL
2710	MILENAKA	1	-	2	26	19	-	-	-
2711	ANKARAOBATO2	1	1974	2	-	-	4.5	-	4.78
2712	ANKARAOBATO	1	1965	1	14.6	6.46	-	-	-
2713	ANKILILOAKA	1	1966	2	13.8	5.12	-	-	-
2714	ANKILILOAKA2	1	1966	2	12.8	2.16	1.7	-	1.28
2715	AMPIHAMY1	1	-	3	22	13.3	-	-	-
2716	ANTSEVA1	1	1965	3	19.6	13.2	-	-	-
2717	NAMABOHA1	1	1966	2	26.88	19	-	-	-
2718	NAMABOHA2	1	-	2	26.8	13.2	-	-	-
2719	AMBAHIZA	1	-	2	30.5	18	-	-	-
2720	AMPASIKIBO	1	-	1	25	15	-	-	-
2721	BELITSAKA SOUTH	1	-	2	24	11	-	-	-
2722	BELITSAKA NORTH	1	-	3	15.2	9.6	-	-	-
2723	ANALAMISAMPY	1	-	1	21.7	11.75	-	-	-
2724	SOAHAZO SOUTH	1	-	2	16	6.15	-	-	-
2725	SOAHAZO NORTH	1	-	2	28	14.3	-	-	-
2726	MANDATSA	1	-	2	20.8	15.55	-	-	-
2727	BETSIOKY NORTH4	1	-	3	90	70	-	-	-
2728	ANDRANOHINALY	1	-	3	219	207	-	-	-
2729	ANDRANOVORY	1	-	3	136	116	-	-	-
2730	BELALANDA	2	-	1	6.9	-	6.4	6.28	6.33
2731	BOTSIBOTSY	2	-	1	9.05	-	7.7	7.65	7.78
2801	ANKILIMALINIKA3	2	1988	1	13.21	-	12.73	12.36	12.56
2802	BENETSE3	2	1985	1	17.78	-	16.02	14.57	14.99
2803	SARIRIAKA4	2	-	1	13.35	-	13.08	11.65	11.05
2804	TSIANISIHA	2	1989	1	16.95	-	16.93	10.25	-
2805	ANKILILAOKA3	2	1971	1	6.33	-	6.28	5.4	6.38
2806	ANKILILAOKA6	2	-	1	4.2	2.5	1.42	0.87	0.66
2807	AMPIHAMY2	2	-	1	10.65	-	9.33	9	-
2808	ANTSEVA2	2	1978	1	10	-	6.57	5.55	6.35
2810	MANDATSA	2	-	1	7.15	-	-	1.1	2.98

Table 3.5.1 Results of Well Inventory (3)

NUMBER	VILLAGE	TYPE (1)	DATE (2)	COND. (3)	DEPTH (4)	W/L (5)	WATER LEVEL NOV-DEC	WATER LEVEL FEB-MAR	WATER LEVEL JUN-JUL
3701	ANDAMASINA VINETA	1	-	3	22.4	8	-	-	-
3702	SAKARAHA PRIMARY SCHOOL	1	-	2	32	11	10.35	10.25	10.36
3703	TRANOKAKY	1	-	3	24	-	-	-	-
3704	MAHABOBOKA	1	-	2	-	-	-	-	-
3705	MAHABOBOKA1	1	1968	3	14	5	-	-	-
3801	SAKARAHA CATHOLIC	2	-	1	16.8	10.62	10.6	10	10.2
3802	SAKARAHA FIVONDRONANA	2	-	1	2.29	-	-	1.63	1.21
3803	SAKARAHA ROAD DEP.	2	-	1	8.2	-	-	7.87	7.76
3804	SAKARAHA GENDARMERIE	2	-	1	10.8	-	-	10.58	10.35
3805	ANADABO	2	-	1	11.66	-	11	11.54	11.73
3806	IABORANO	2	-	1	2.45	-	0.4	-	0.02
3807	MIARY LAMATIHY	2	-	1	3.3	-	2.22	-	1.6
3808	BEREKETA	2	1985	2	8.4	-	6.9	6.9	7.07
4701	TANANDAVA	1	1968	2	15.48	5.6	-	-	-
4702	ANKAZOABO	1	1969	3	31	5	-	-	-
4801	TANANDAVA	2	-	1	6.14	-	5.85	-	5.8
4802	ANKAZOABO1	2	-	1	5.43	-	4.75	-	4.3
4803	ANKAZOABO2	2	1977	1	12.24	-	11	-	10.7
4804	ANKAZOABO3	2	-	1	14	-	13.02	-	12.79
4805	ANKAZOABO4	2	-	1	5.54	-	4.1	-	4.18
4806	TANDRANO	2	-	3	7.95	-	-	-	-
4807	TANDRANO	2	-	1	11.07	-	10.06	-	6.8
4808	BERENTY BETSILEO	2	1975	3	17.2	-	-	-	-
5701	AMBAHIKILY1	1	1989	2	17.5	-	2.25	-	1.75
5702	ANDRANOMANINTSY1	1	1966	3	11.6	4	1.75	-	2.15
5703	BEFANDRAIANA SUD	1	1975	1	36	25	-	-	-
5704	BEFANDRAIANA SUD2	1	1966	3	27	24.5	-	-	-
5705	ANKILIMASY	1	1968	2	36	31.2	-	-	-
5706	ANDRANOTERAKA NORTH	1	1966	2	18	9	-	-	-
5707	ANDRANOTERAKA SOUTH	1	1966	2	14.5	8.5	-	-	-
5708	MAROFOROHA	1	1966	3	12.5	3	-	-	-

Table 3.5.1 Results of Well Inventory (4)

NUMBER	VILLAGE	TYPE (1)	DATE (2)	COND. (3)	DEPTH (4)	W/L (5)	WATER LEVEL NOV-DEC	WATER LEVEL FEB-MAR	WATER LEVEL JUN-JUL
5709	SIHANAKA	1	1966	2	21.8	13.8	6.07	3.18	-
5710	BEKIMPAY	1	1966	2	13.1	5.1	3.9	-	-
5711	BEMOKA	1	1968	3	12	5.5	-	-	-
5712	BASIBASY	1	1966	3	14	8	-	-	-
5713	ANTANIMIEVA1 MARKET	1	1973	2	14	8	-	-	-
5714	ANTANIMIEVA2 HOSPITAL	1	-	2	16	7	-	-	-
5715	antanimieva	1		1	160	aretian			
5801	MOROMBE	2	1968	1	6.05	-	4.07	-	4.36
5802	BELITSAKA	2	1977	1	4.87	-	1.65	-	1.67
5803	NAMATOA1	2	-	1	4.19	-	3.15	-	2.97
5804	NAMATOA2	2	1973	1	4.56	-	3.6	-	1.9
5805	AMBAHIKILY1	2	-	1	3.29	-	1.25	-	1.15
5806	AMBAHIKILY2	2	-	1	1.45	-	1.59	-	1.69
5807	AMBAHIKILY3	2	-	1	3.94	-	1.66	-	1.62
5808	TSIANIHY	2	1968	1	6.6	-	4.65	-	3.06
5809	AMBALAMOA	2	1959	1	6.55	-	4.55	-	2.63
5810	ANDRANOMANINTSY	2	1966	3	4.39	1.75	-	-	-
5811	BERANALA	2	1987	1	2.94	-	2.24	-	2.34
5812	TANANDAVA1	2	-	1	7.74	-	2.16	-	2.87
5813	TANANDAVA2	2	-	1	4.84	-	3.74	-	2.86
5814	TANADAVA3	2	-	1	6.64	-	1.44	-	1.86
5815	AMBIKY	2	1989	1	2.5	-	2.1	-	1.85
5816	ANKILIFOLO	2	1986	1	10	-	2.65	4.45	4.69
5817	AMPOZA1	2	1979	1	10.7	-	6	5.96	5.81
5818	MANOY	2	1984	1	11	-	8.65	-	7.86
5819	ANTRANOSATRA	2	1957	1	7.9	-	0	-	-
5820	BEFOLY	2	1973	1	9.75	-	5.55	-	5.35
5821	ANDRANOTERAKA SOUTH	2	1986	1	6.7	-	5.3	-	5.26
5822	BASIBASY	2	1973	2	8	-	4.6	-	3.71
5823	MANGOTROKA	2	1969	1	4.7	-	4.6	1.6	2.4
5824	ANTANIMIEVA3	2	-	1	-	-	-	-	-

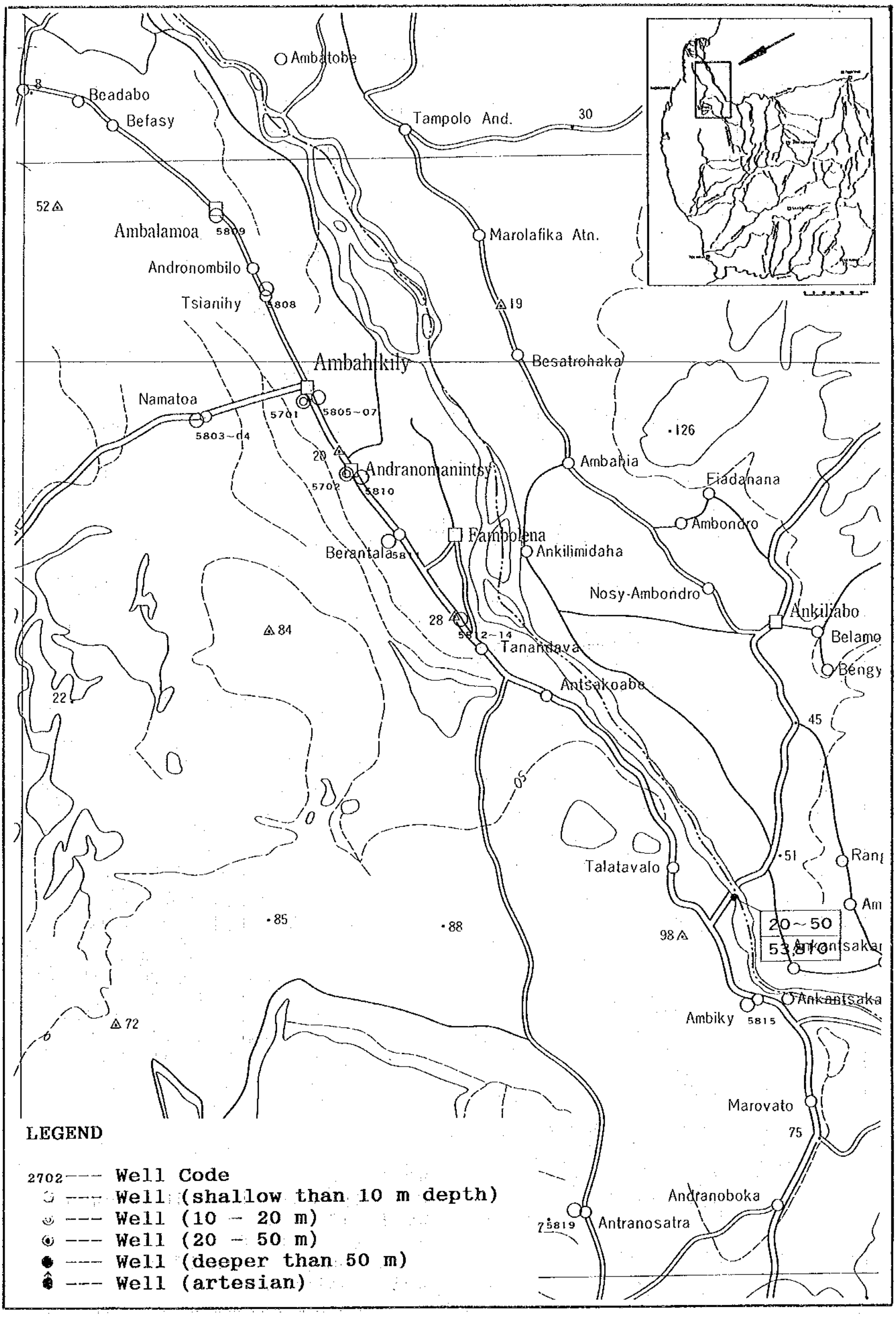


Fig. 3.5.1 Location of Existing Wells (1)

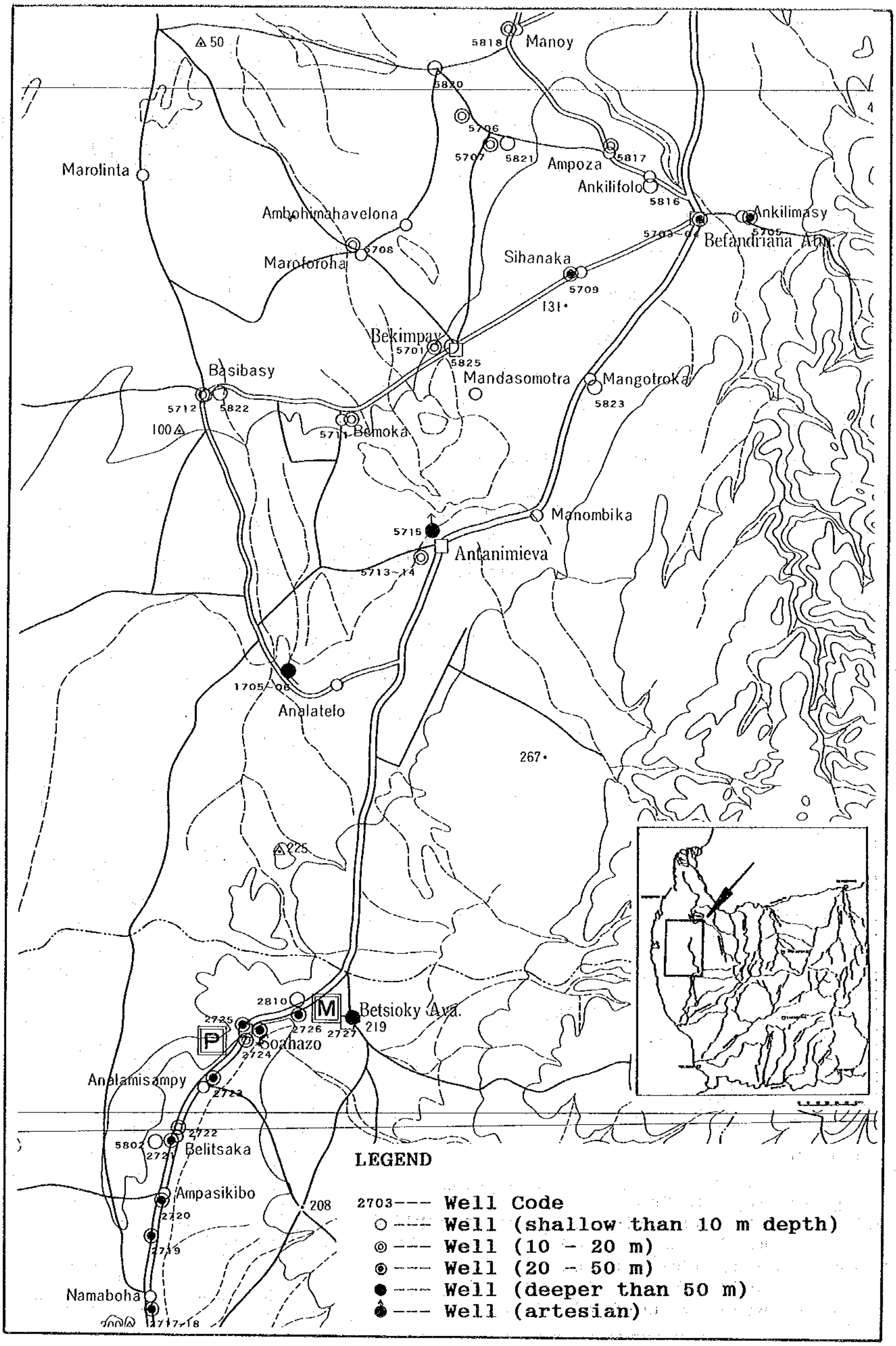


Fig. 3.5.1 Location of Existing Wells (2)

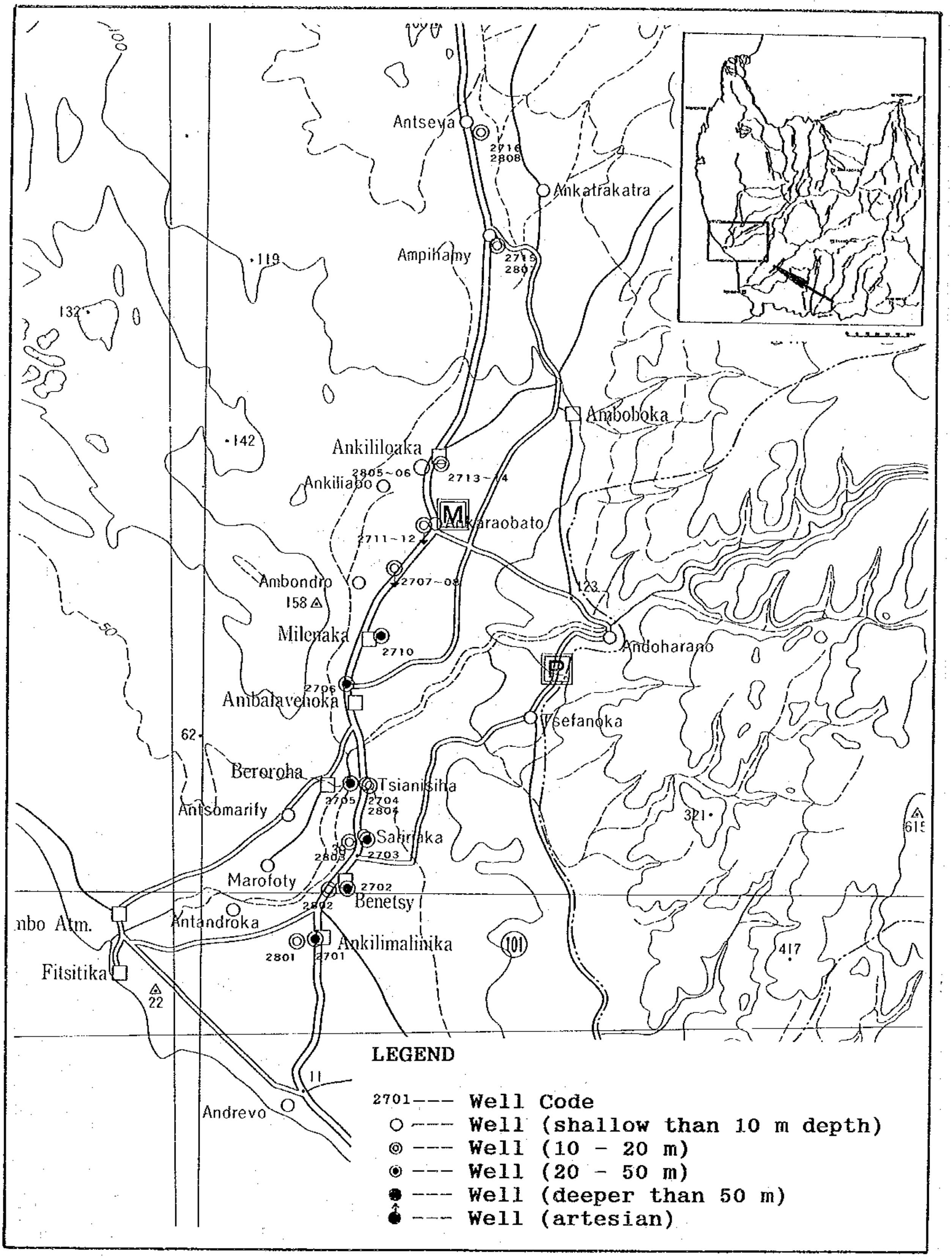


Fig. 3.5.1 Location of Existing Wells (3)

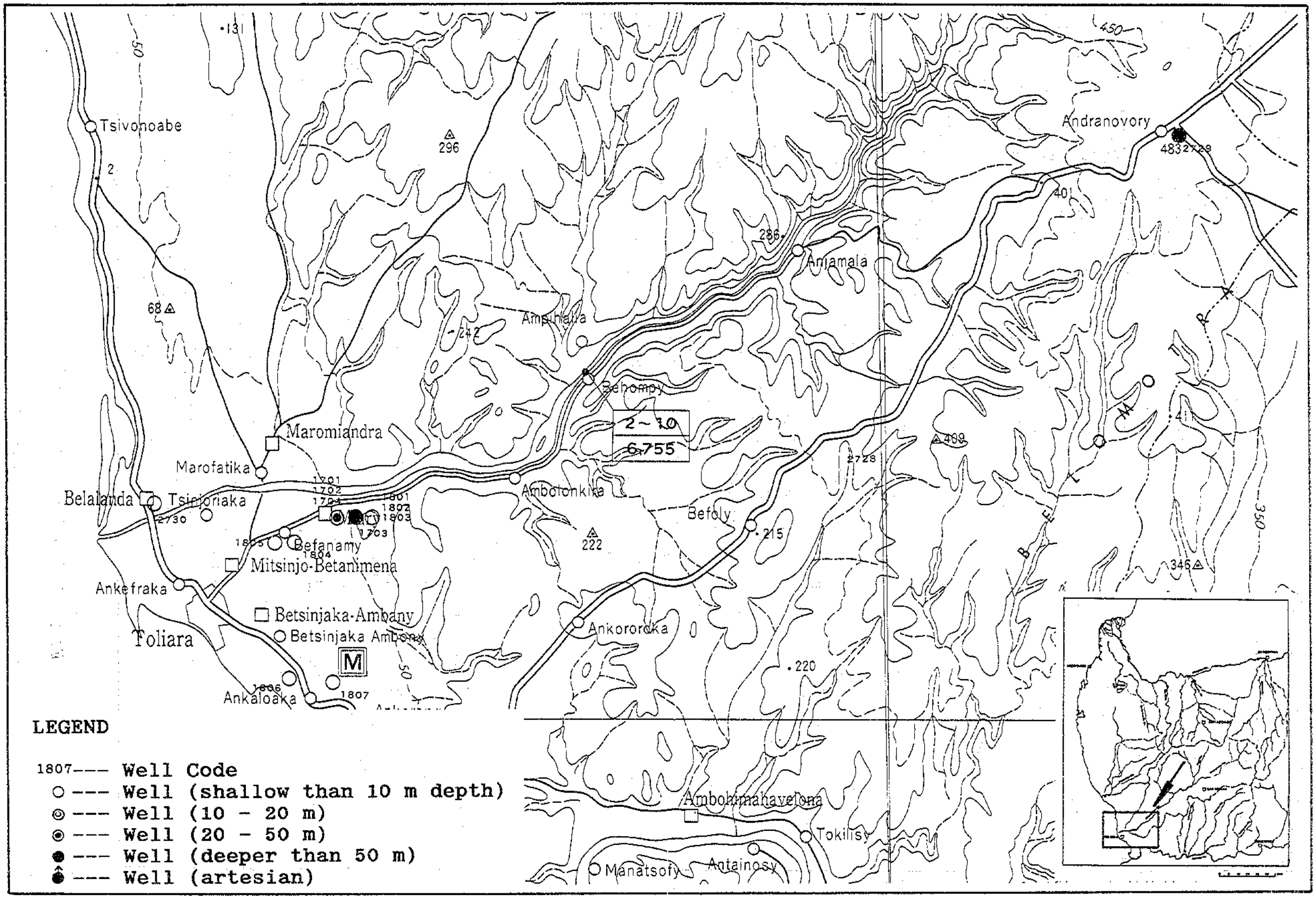


Fig. 3.5.1 Location of Existing Wells (4)

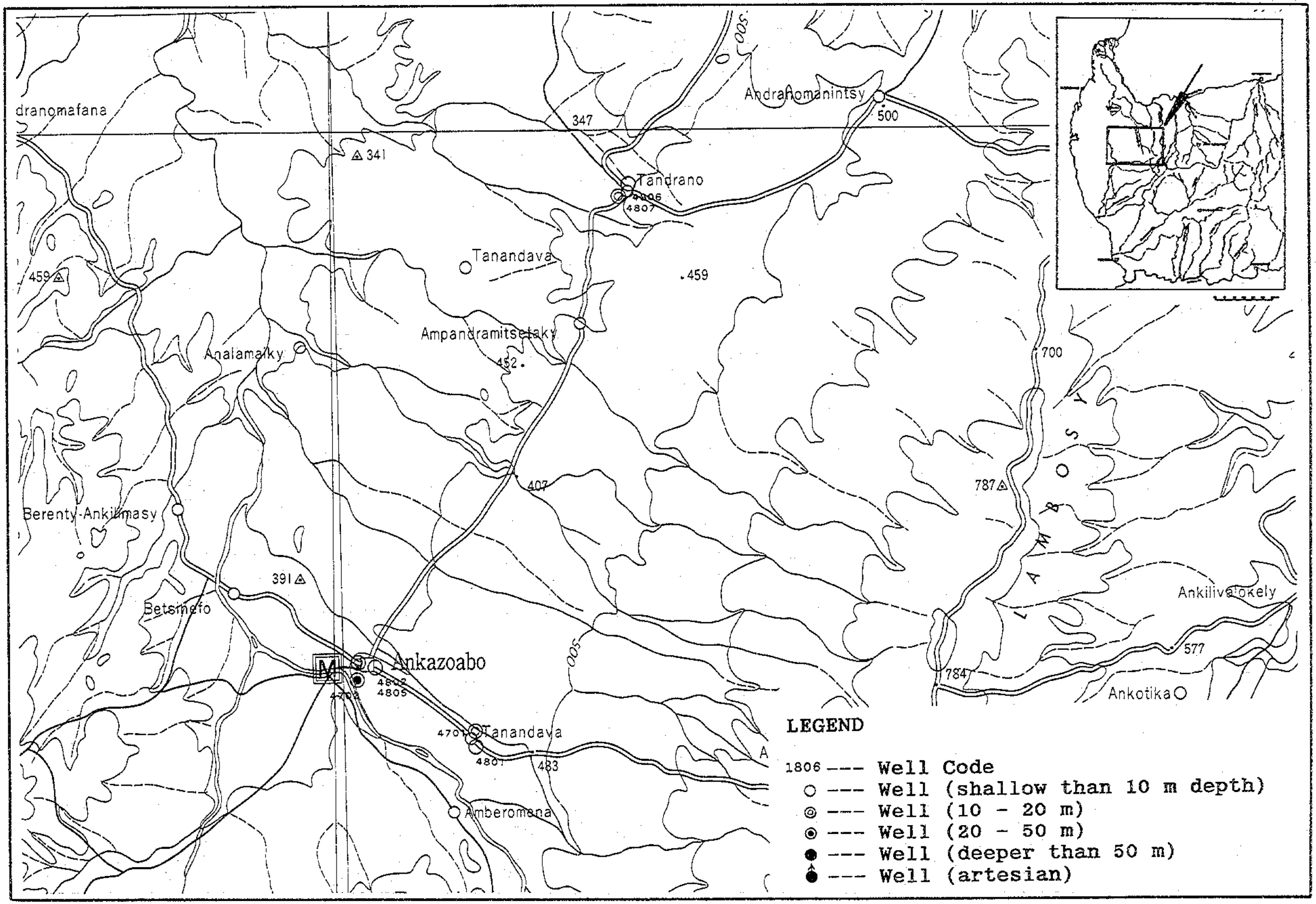


Fig. 3.5.1 Location of Existing Wells (5)

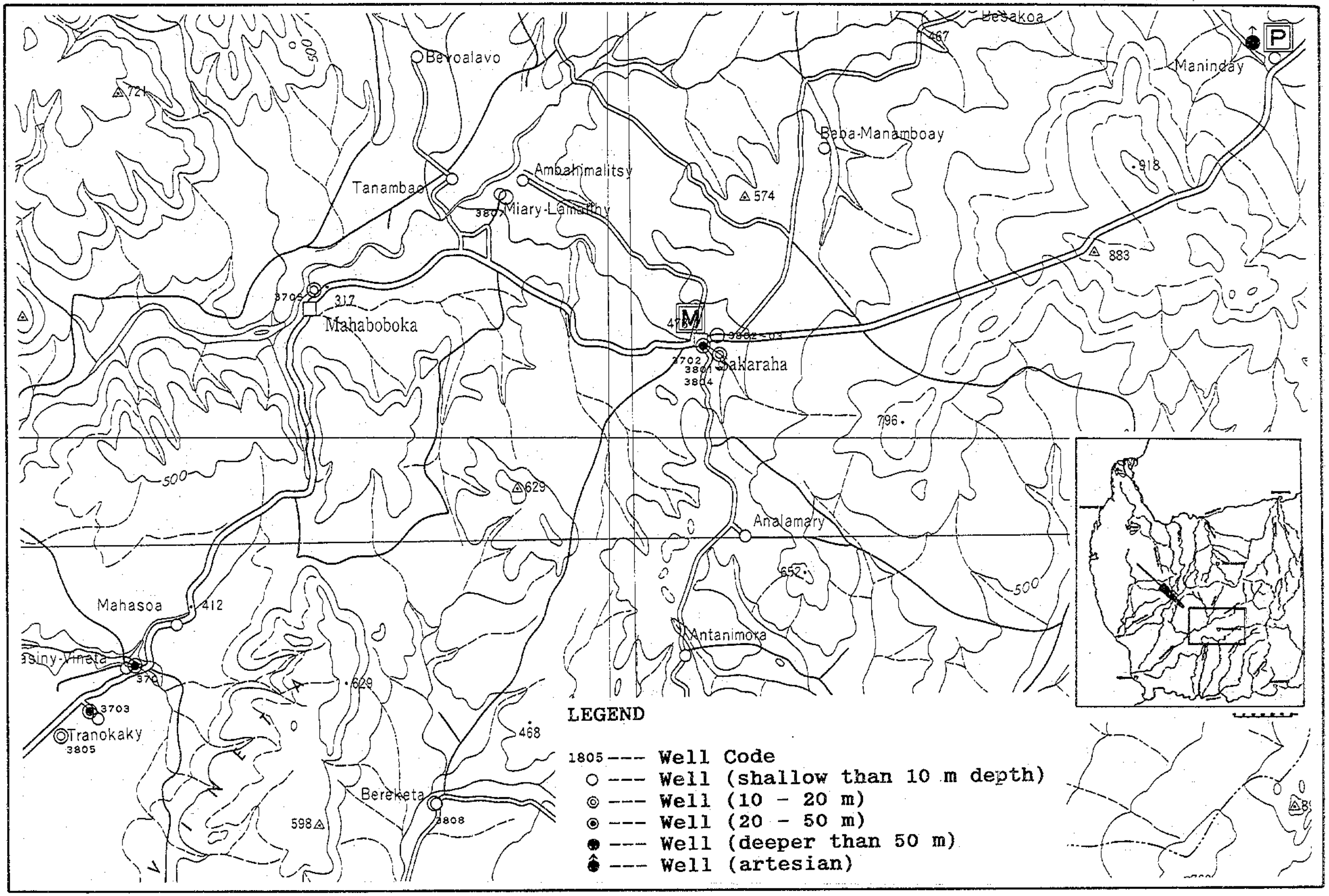


Fig. 3.5.1 Location of Existing Wells (6)

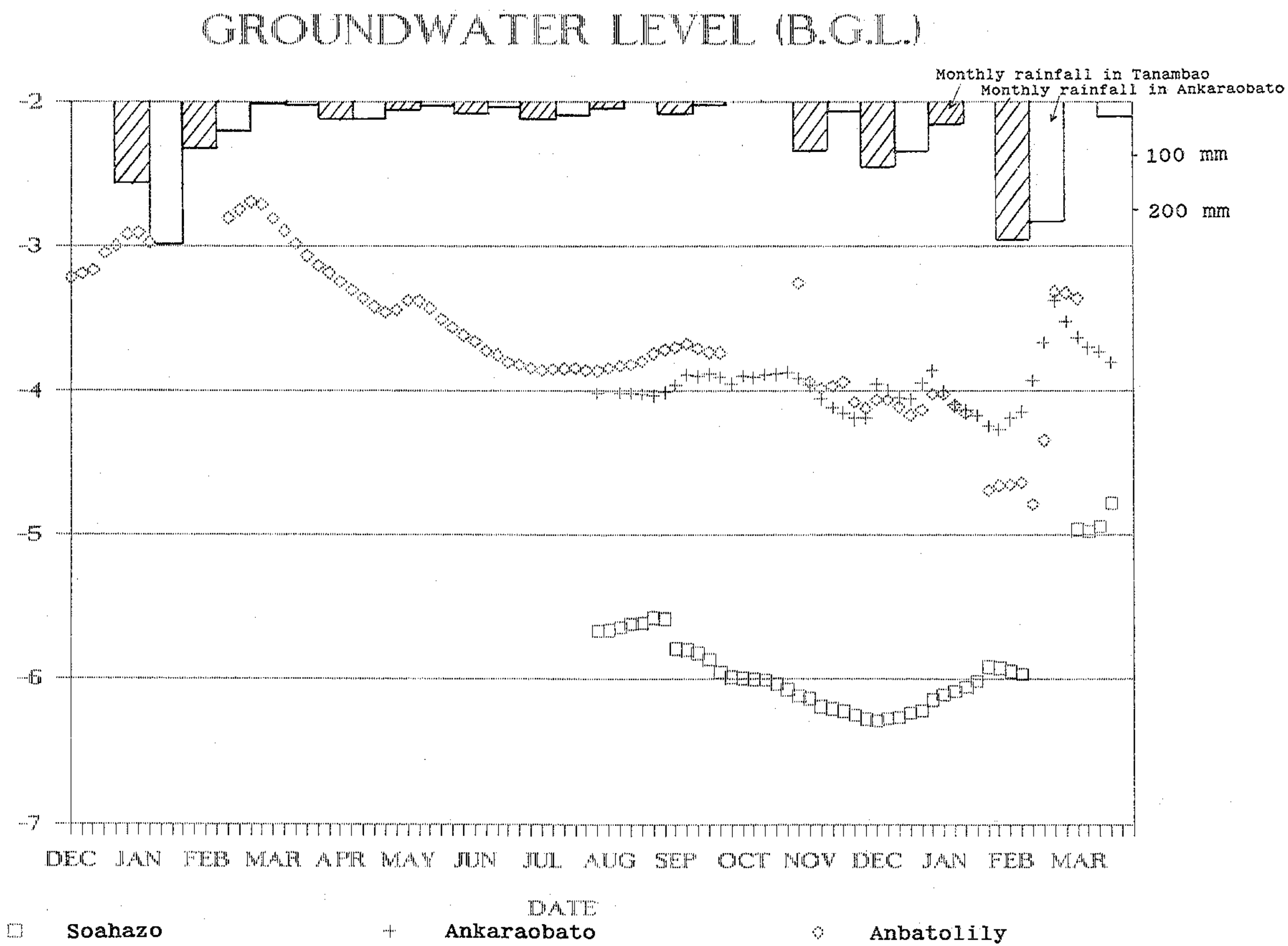


Fig. 3.5.2 Results of Continuous Leveling (1)

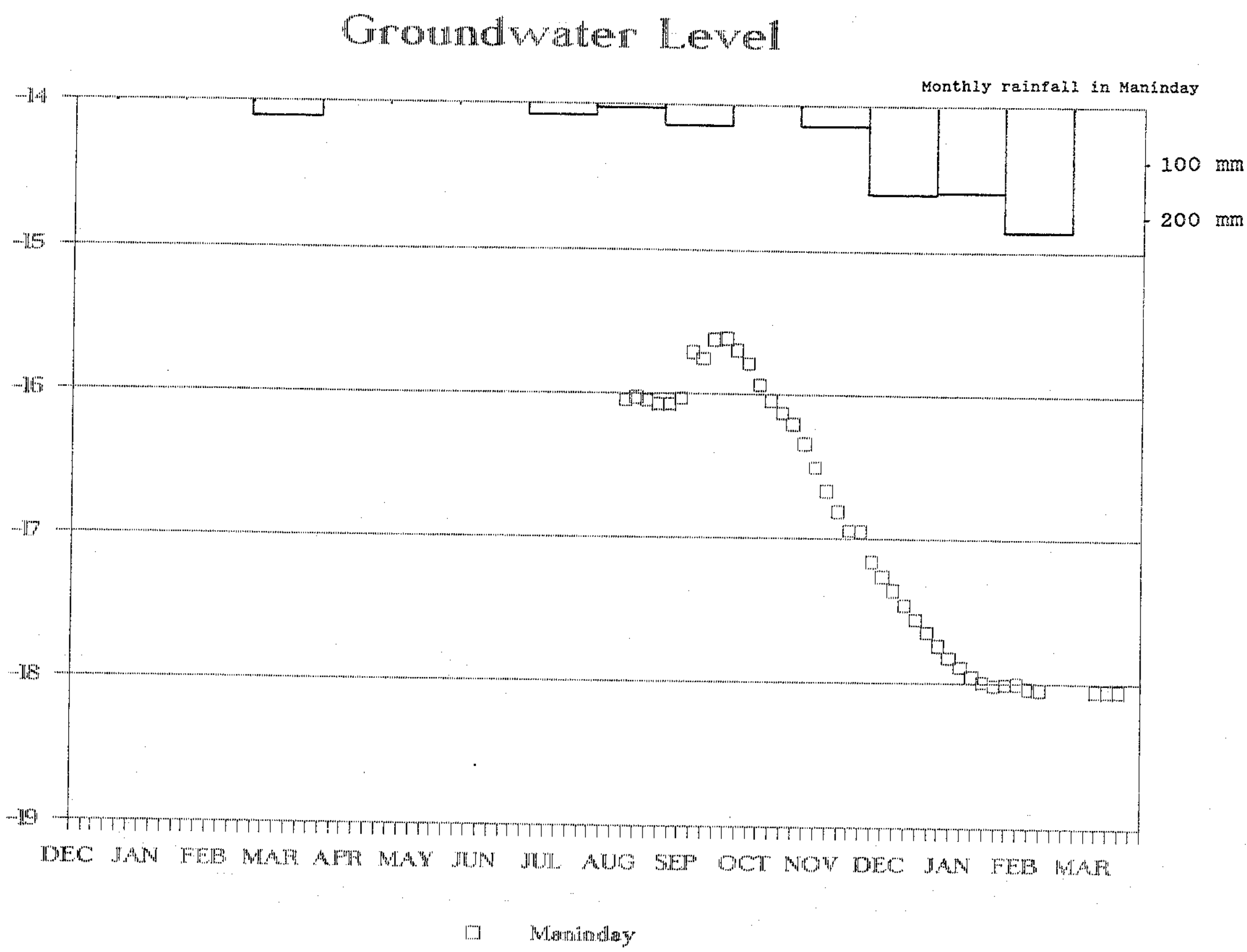


Fig. 3.5.2 Results of Continuous Leveling (2)

3.6 Geophysical Prospecting

In this study, two methods of geophysical prospecting were used: electrical resistivity sounding and VLF magneto-telluric survey. The electrical resistivity sounding employed the Gish-Rooney method with Wenner's electrode configuration and Mc-OHM type resistivity meter. The VLF magneto-telluric survey using the WADI type of electro-magnetic meter was carried out mainly to investigate groundwater from faulted block areas and fractured zones (See Fig. 3.6.1).

3.6.1 Electrical Resistivity Sounding

Electrical resistivity sounding, with prospecting depth of 50 to 300m, was carried out on 139 survey points in 49 sites during Phase I, and 110 survey points in 33 sites during Phase II. Those survey sites and survey points were selected based on the hydrogeological conditions resuling from the LANDSAT and SPOT image data analysis, the aero-photo interpretations, geological field reconnaissance and the reviews and analysis of existing hydrogeological data and information. The results of electrical resistivity sounding were analyzed hydrogeologically, and the outcome of the analyses can be found as hydrogeological cross sections in Supporting Report(1) of Volume 3.

From the results of electrical resistivity sounding and its hydrogeological analyses, the sites and depth for test drillings were determined. The test drillings and the hydrogeological analyses of electrical resistivity sounding permit the following considerations.

(a) The variation of resistivity with depth generally conforms to the stratigraphy, and a comparatively higher resistivity value indicates a more permeable layer, which probably is a productive aquifer.

(b) In areas consisting mainly of Isalo Formations and calcareous deposits of the Jurassic to Eocene, an irregular variation of resistivity values is found in neighboring survey points, even though both the ground surface and the bedding of the layers are nearly flat. This may be caused by the continental sedimentary environment of the Isalo

Formations and the irregular deposition of neritic calcareous materials such as lenticular limestone, marly limestone, marl,marly sandstone and marly siltstone or mudstone (see Figs. 3.6.2 and 3.6.3).

(c) Similar composition of lithofacies may sometimes result in different electric resistivitiy values. Therefore, it is important to interpret the results of electrical resistivity sounding based on the results of detailed hydrogeological reconnaissance. For example, in spite of the generally low electric resistivity values ranging from 10 to 50 ohm-m (Ω-m) in the test drilling sites of villages numbered 22, 23, 34, 55, and 65, existence of highly productive aquifers were confirmed by the test drilling (see Figs. 3.6.4 - 3.6.8).

(d) When the electric resistivity values are between 10 to 50 ohm-m, in the study area, the lithofacies generally consist of alternation of sandstone, marl or mudstone and marly limestone. The productivity of those aquifers is generally higher than that suggested by the electric resistivity values.

(e) In such areas as Tranokaky (95) where lithofacies con sist of fractured or hard compact basaltic rocks and weakly weathered sandstone or mudstone of the Cretaceous, the hydrogeological interpretation of the results of electric resistivity sounding is very difficult because of the similar electric resistivity values in those volcanic rocks and sedimentary rocks (see Fig. 3.6.9).

(f) In the high plateau area consisting of thick calcareous sediments of the Lower to Middle Eocene, covering Andranovory (77), Andranohinaly and Befoly(78), it is difficult to apply the hydrogeological interpretations which classify fractured or porous limestone as highly productive aquifer and compact or massive limestone as poor aquifer, because of the similar electric resistivity values in those fractured or porous limestone and compact or massive limestone.

It is, therefore, very important to interpret the results of electrical resistivity sounding based on the results of

SPOT image and aero-photo analyses and detailed hydrogeological reconnaissance.

(g) In the Antanimieva area, there is one artesian well with a discharge capacity of about $400m^3/h$. Its lithology was obtained by the electrical resistivity sounding, revealing that the marly limestone(80Ω-m) at 120m below the ground surface was a highly productive confined aquifer and the marl or marly limestone (20Ω-m) with a thickness of about 50m was the confining layer (see Fig. 3.6.10).

As shown in Fig.3.6.11, the hydrogeological condition in the Betsioky-Ayaratra area, as interpreted from the results of electrical resistivity sounding, is almost similar to that in the Antanimieva area, and a highly productive confined aquifer is expected between 100 and 150m below ground surface.

(h) In the coastal area between Manombo Atm(63) and Toliara, the problems of drinking water due to salty water intrusion have been always raised by the inhabitants. A detailed electric resistivity sounding was, therefore, carried out in order to clarify the hydrogeological conditions in the area.

Figs. 3.6.12 and 3.6.13 show the results of the detailed electrical resistivity sounding conducted in the model sites in the area. As can be inferred from these figures, the area inhabitants use an unsteady shallow groundwater of the Herzberg's lens which is formed in the limestone or marly limestone layer. Therefore, the recommendable water supply system in the coastal area is one which employs a shallow dug well or a shallow borehole with hand pump.

(i) As the conclusion of the results of electrical resistivity sounding and its hydrogeological interpretation, along with the results of test drilling and pumping test, the following correlations between apparent electric resistivity values and lithofacies are generally found in the Study Area.

Lithofacies	Resistivity (ohm-m)	Remarks
Clayey marl	3-6........	
Marl	5-25.......	Generally poor
Sandy marl	4-35.......	aquifer
Mudstone	10-30......	
Silty or muddy sandstone	8-30.......	Locally productive aquifer
Marly sandstone	20-82......	
Alternation of sandstone and marl or mudstone	17-384.....	In general, highly productive aquifer
Marly limestone	33-99......	
Sandstone & gravelly sandstone	80-2,200...	Highly productive aquifer (if less than 1,000 Ω-m)
Limestone	95-6,030...	
Basaltic rocks	28-1,120...	

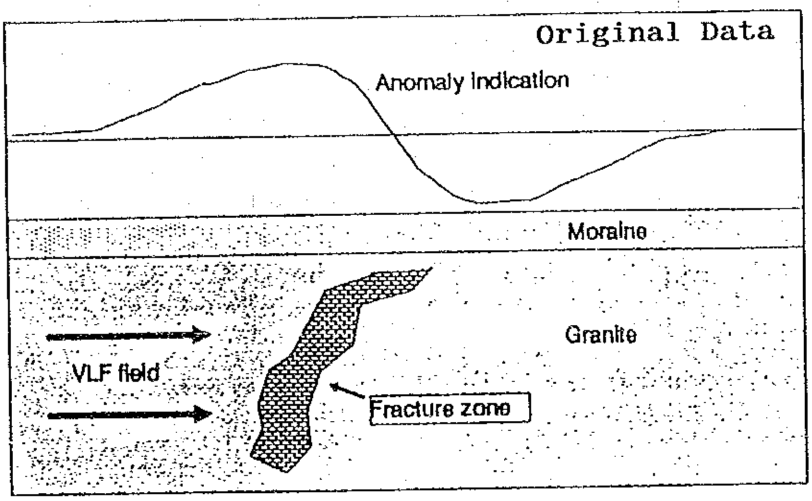
The groundwater potentiality in the Study Area, shown in the hydrogeological map, was evaluated based on the above mentioned considerations of the results of electical resistivity sounding and the corresponding hydrogeological interpretation.

3.6.2 VLF Magneto-Telluric Survey (WADI Type)

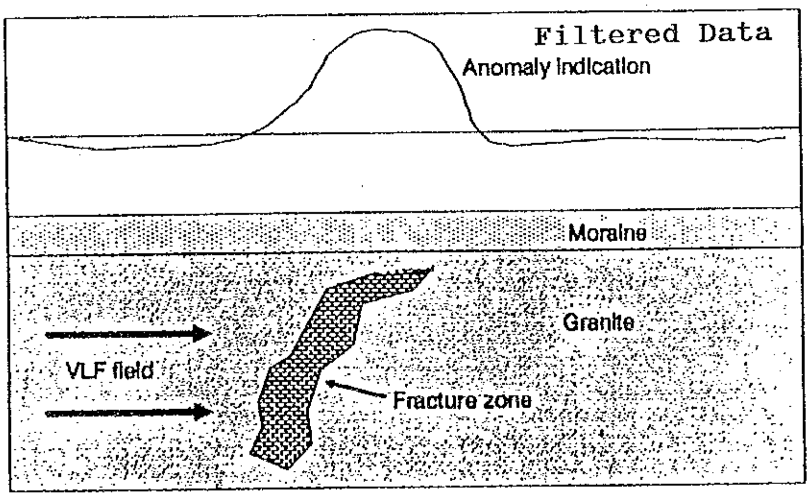
Generally speaking, the VLF magneto-telluric survey, or the so called electro-magnetic method, is one of the useful ways to investigate speedily dipping geological structures that differ from their surroundings with regard to electrical resistance. This survey method is, thus, well suited for groundwater prospecting in fracture zones.

As shown in the hydrogeological map, there are many faults and fracture zones in the Study Area, and some of them control directly or indirectly the existence of groundwater in aquifers. In this study, the very portable WADI VLF instrument was, therefore, employed to investigate ground-water controlled by those faults or fracture zones.

Typical anomaly indications of original data and filtered data designed in the WADI VLF instrument are as follows.



The following figure shows how a water-bearing fracture zone in rock generates a secondary field that causes a typical anomaly indication on the WADI instrument.

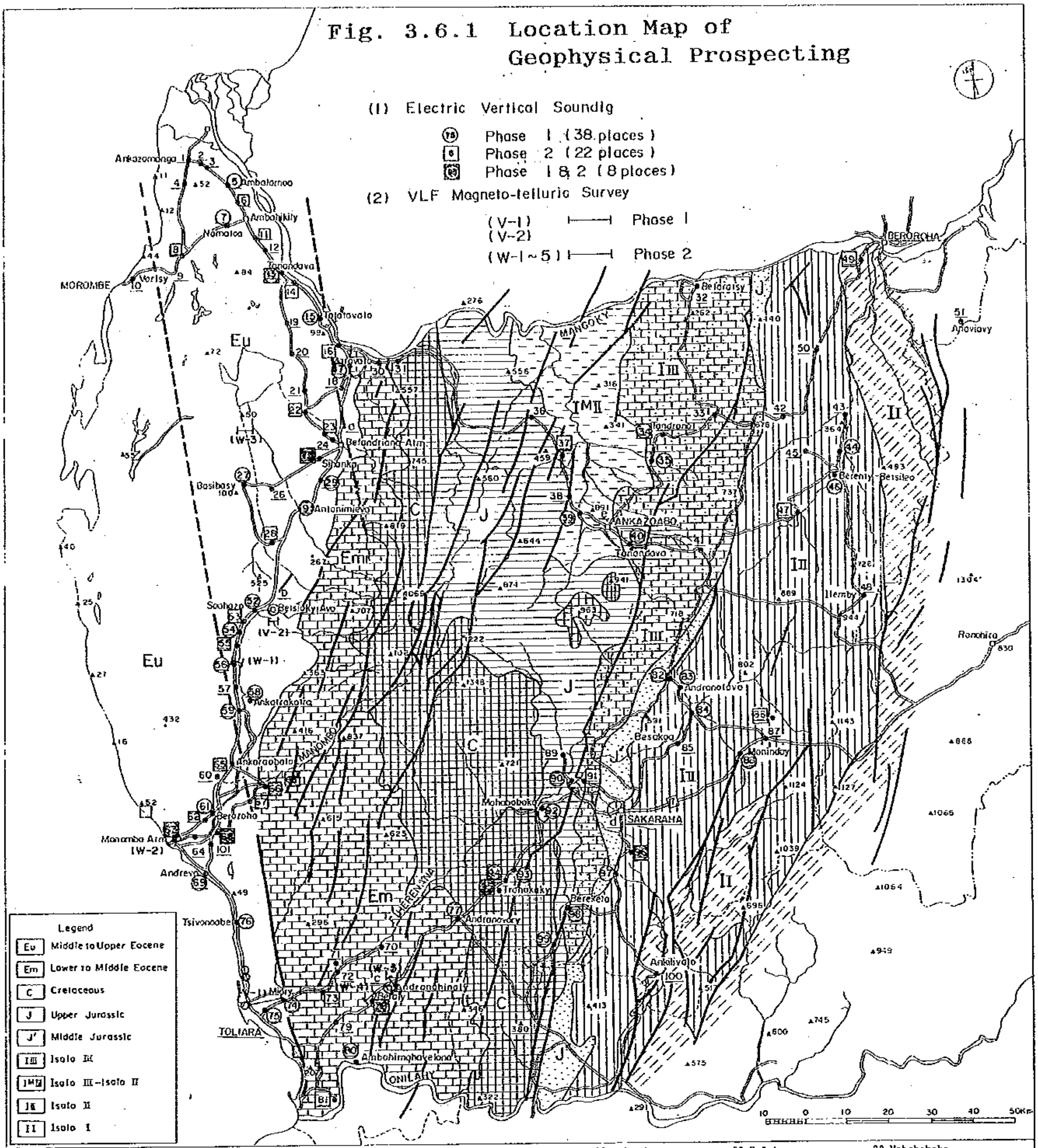


This magneto-telluric survey was carried out on 12 lines of 8 sites which were selected as the representative survey sites where faults or fracture zones were presumed to lie. The results of this survey with computed analysis records are given in Supplementary Report(1) of Volume 3.

Fig. 3.6.14 shows the hydrogeological cross section of Toliara Plain interpreted from the results of electrical resistivity sounding and VLF magneto-telluric survey. As shown in this Fig.3.6.14, it was confirmed that this survey method would be useful in probing a fault or a fracture zone. Actually, the main source of the water supply system in Toliara City is the groundwater from limestone aquifer at Miary, which is controlled by Toliara fault and its fractured zone.

However, the VLF WADI instrument performed poorly against strong sunlight in the field work of the Study Area. Accordingly, this survey method was used in only 8 sites.

Fig. 3.6.1 Location Map of Geophysical Prospecting



No Villages

I. Fiv. MOROMBE

1 Ankazomanga
2 Beadabo
3 befasy
4 Ankilifolo(1)
5 Ambalamoa
6 Tsianihy
7 Namatoa
8 Mangolovolo
9 Ankida
10 Vorisy
11 Andranomanitsy
12 Berantala
13 Tanandava
14 Antsakoabe
15 Talatavalo
16 Ambiky
17 Marovato
18 Andranoboka
19 Satrambondro
20 Mahavozokely
21 Antranosatra
22 Manoy
23 Ampoza
24 Ankilifolo(2)
25 Sihanaka
26 Bemoka
27 Basibasy
28 Analatelo
29 Mangotroka
30 Nosy-Ambositra
31 Tsiarimpioke

II. Fiv. ANKAZOABO ATM

32 Betaratsy
33 Andranomanintsy
34 Tandrano
35 Ampandramitsetaky
36 Andranomafana
37 Mamakiala
38 Berenty-Ankilimasy
39 Betsinefo
40 Tanandava
41 Ampoza
42 Ipetsa Atm
43 Mandabe Atm
44 Soatanimbary
45 Sahanory Atn
46 Berenty-Betsileo
47 Ankilivalokely
48 Ilemby

III. Fiv. BEROROHA

49 Tanandava-Antaifasy
50 Anjamitikitra
51 Anaviavy

IV. Fiv. TOLIARA I / II

52 Soahazo
53 Analamisampy
54 Belitsaka
55 Ampasikibo
56 Namaboha
57 Antseva
58 Ankilimiavotoka
59 Ampihamy
60 Ambondro
61 Beroroha
62 Antsoamarify
63 Manoabo-Atm
64 Antandroka
65 Ankaraobato
66 Andoharano
67 Tsefanoka
68 Benetsy
69 Andrevo
70 Anjamala
71 Ampihalia
72 Behoapy
73 Ambolonkira
74 miary
75 Befanamy
76 Tsivonoabe
77 Andranovory
78 Befoly
79 Ankororoka
80 Ambohimahavelona
81 Manoroka
101 Ankilimalinika

V. Fiv. SAKARAHA

82 Iaborana
83 Andranolava
84 Lambomakandro
85 Besakoa(1)
86 Besakoa(2)
87 Ampandra
88 Maninday
89 Bevoalavo
90 Tanambao
91 Ambahimalitsy
92 Mahaboboka
93 Mahasoa
94 Andamasiny-Vineta
95 Tranokaky
96 Analamary
97 Antaninora
98 Bereketa
99 Ankilimitraloka
100 Ankilivalo

a Befandriana
b Betsioky Nord
c Andranohinaly
d Sakaraha
e Ankazoabo

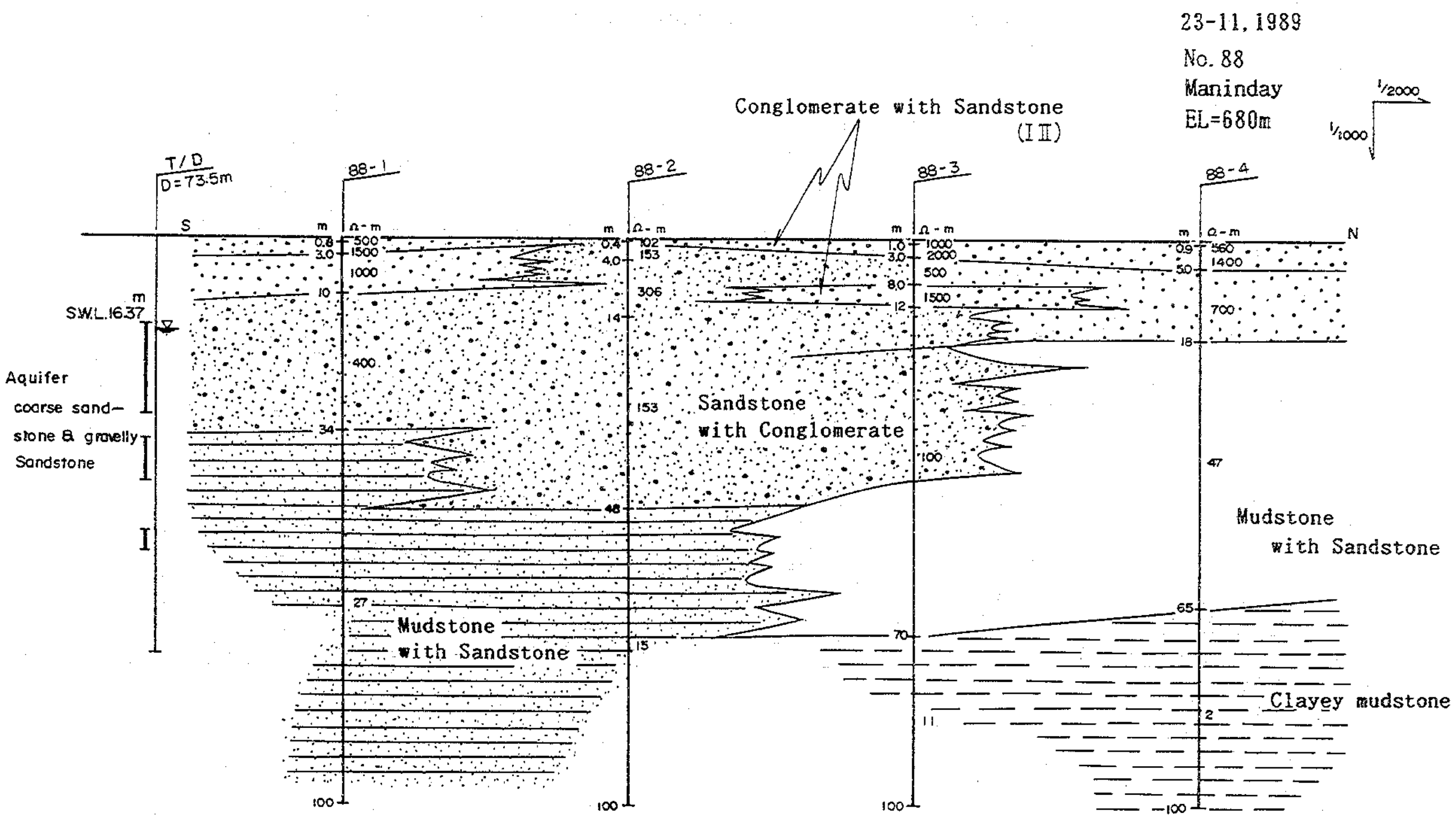


Fig. 3.6.2 Hydrogeological Section of Maninday Area (88)

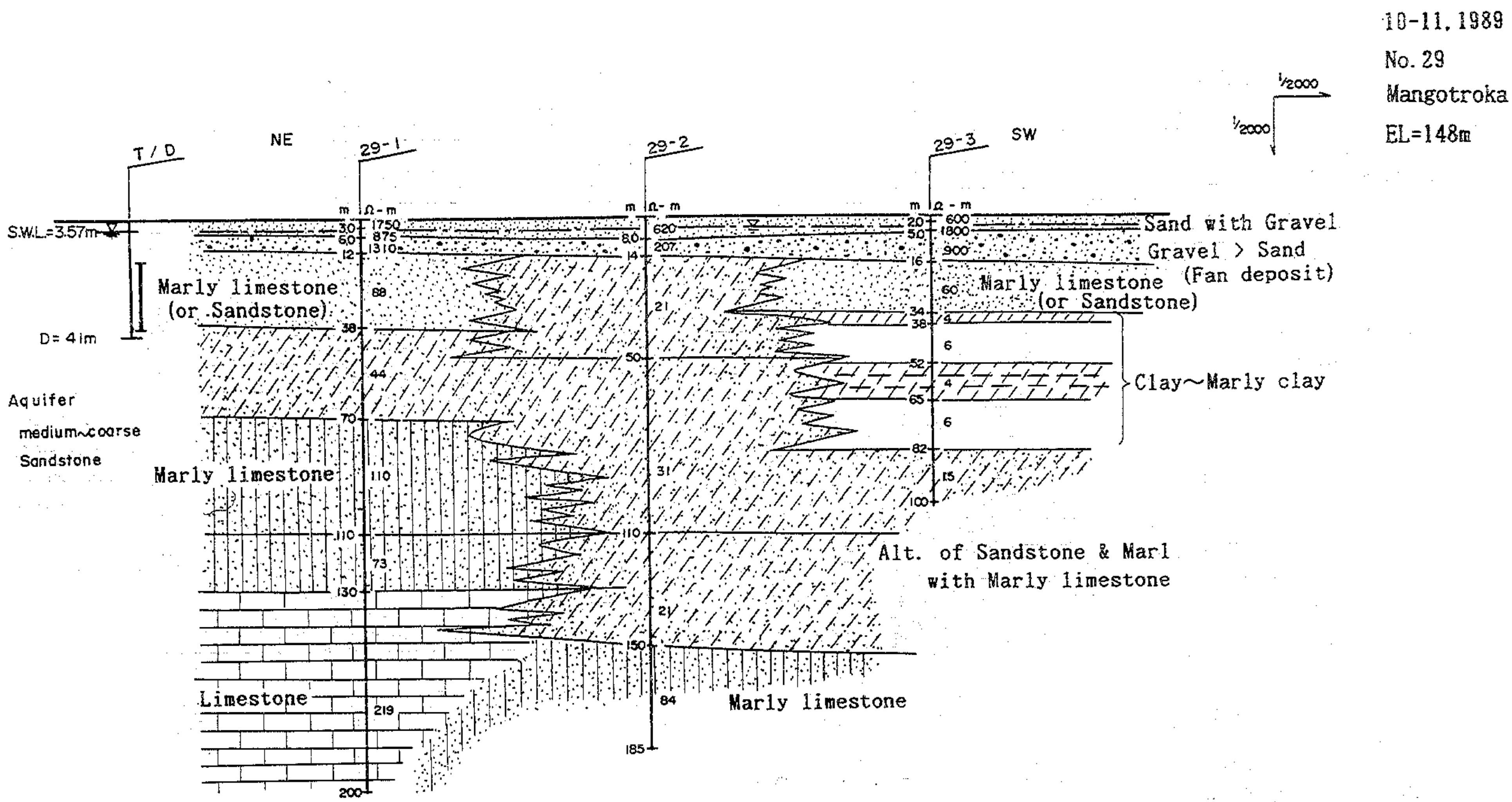


Fig. 3.6.3 Hydrogeological Section of Mangotroka Area (29)

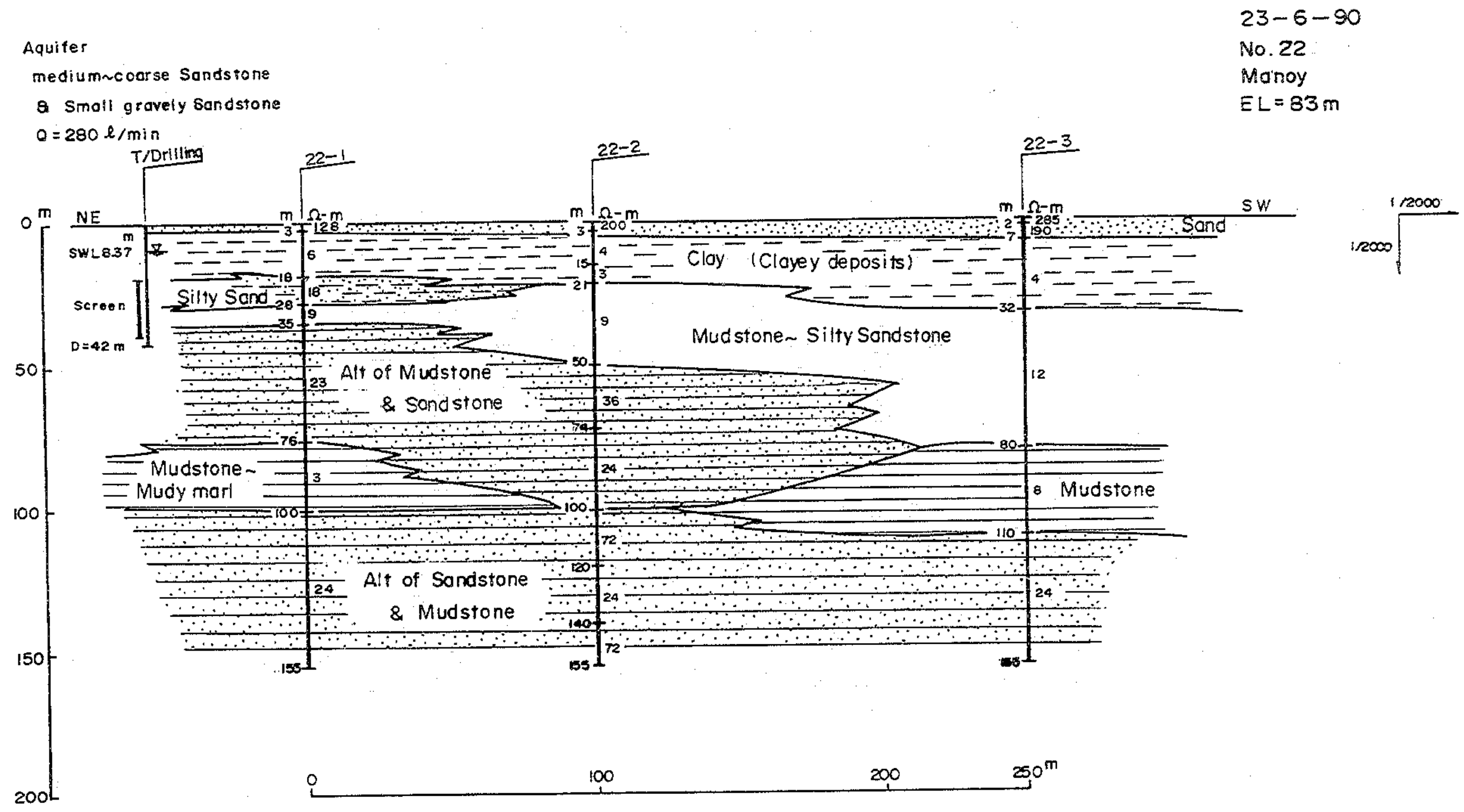


Fig. 3.6.4 Hydrogeological Section of Manoy Area (22)

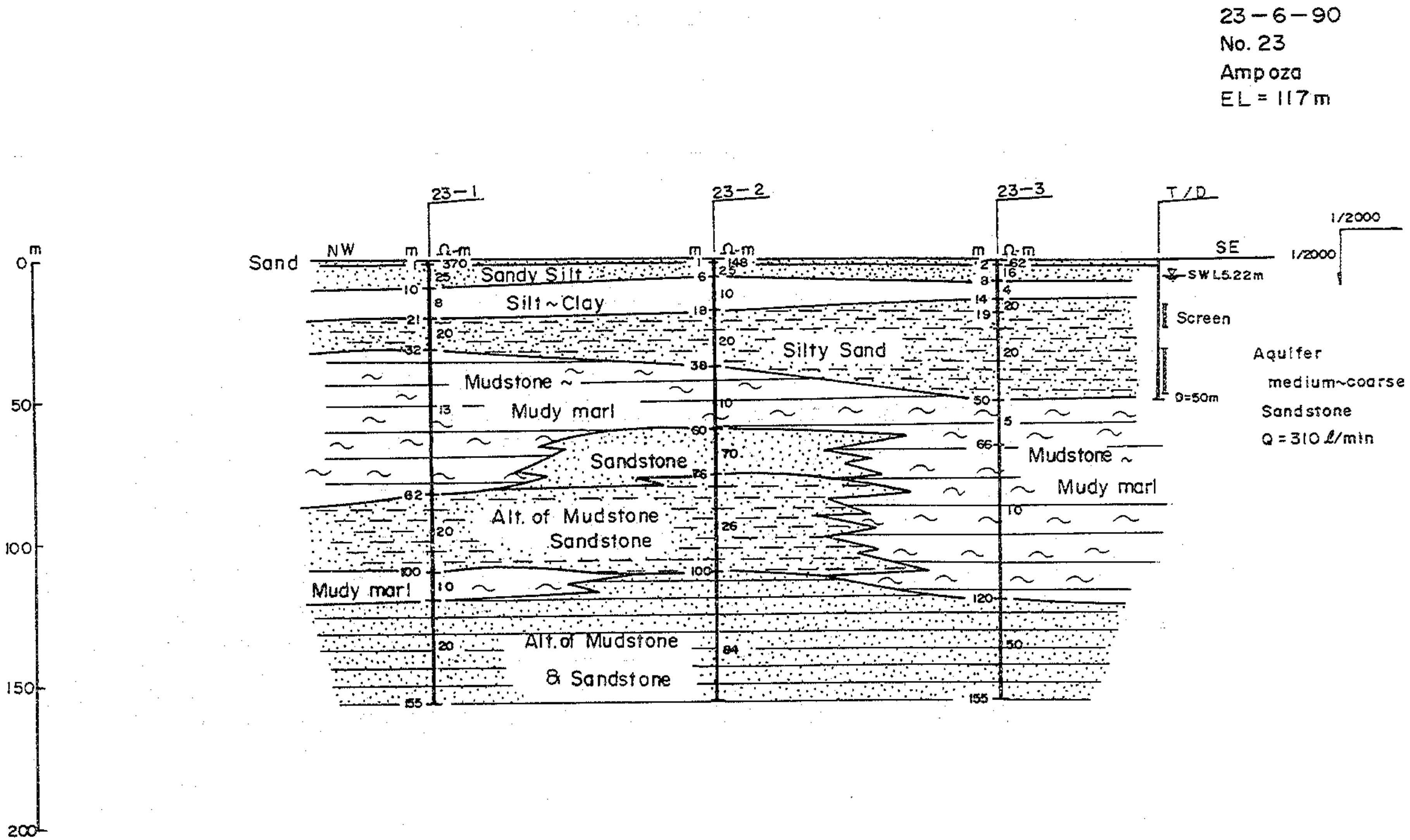


Fig. 3.6.5 Hydrogeological Section of Ampoza Area (23)

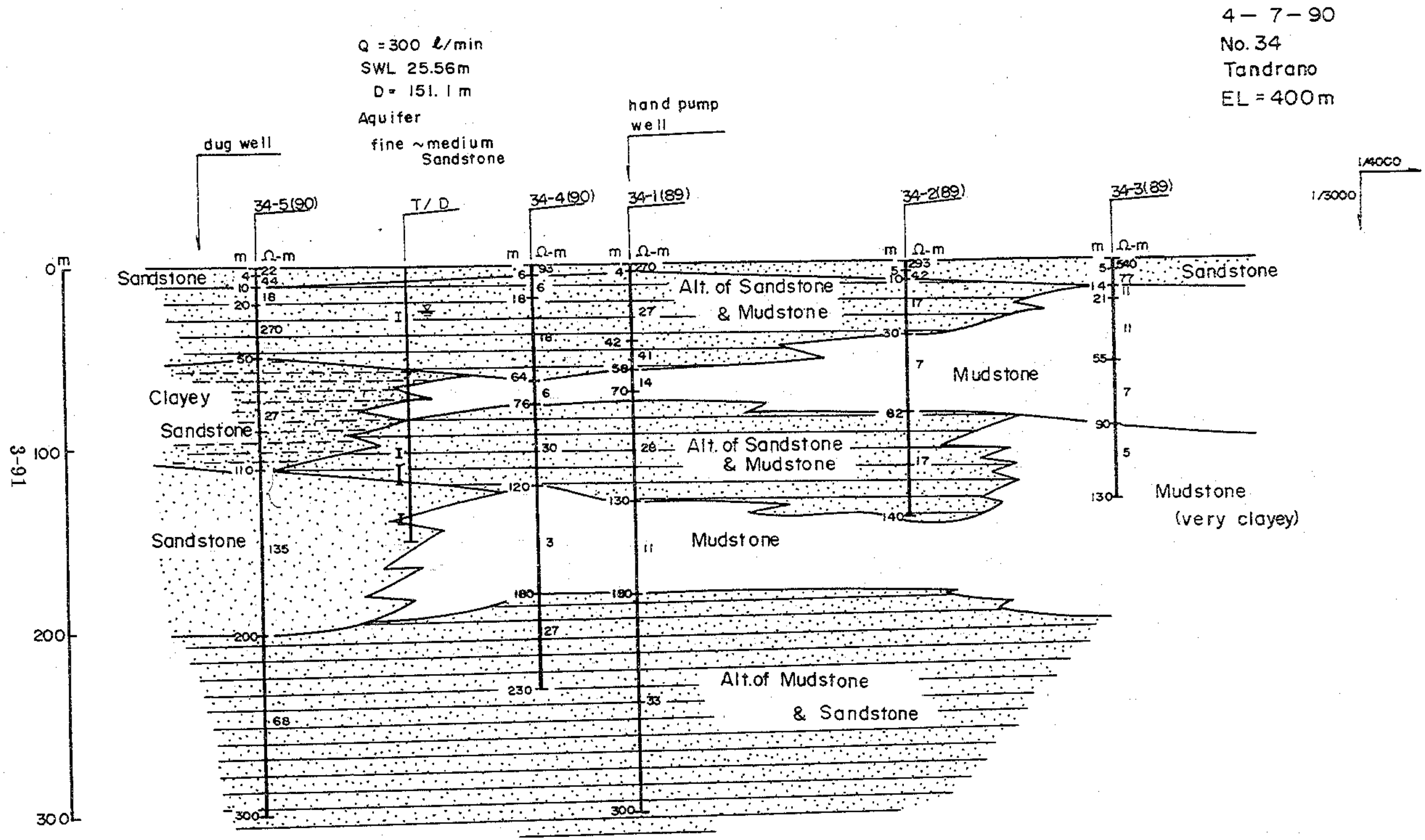


Fig. 3.6.6 Hydrogeological Section of Tandrano Area (34)

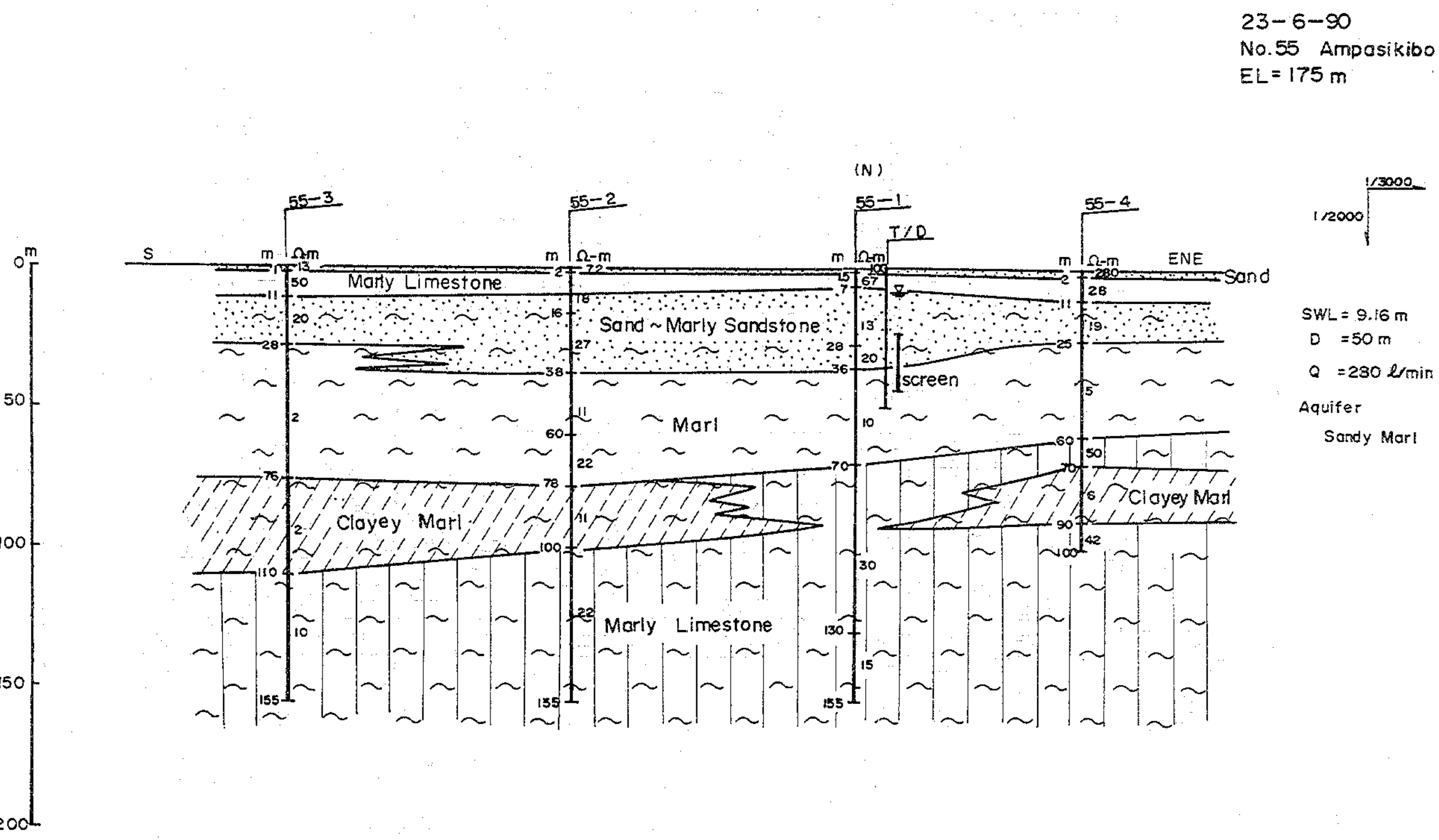


Fig. 3.6.7 Hydrogeological Section of Ampasikibo Area (55)

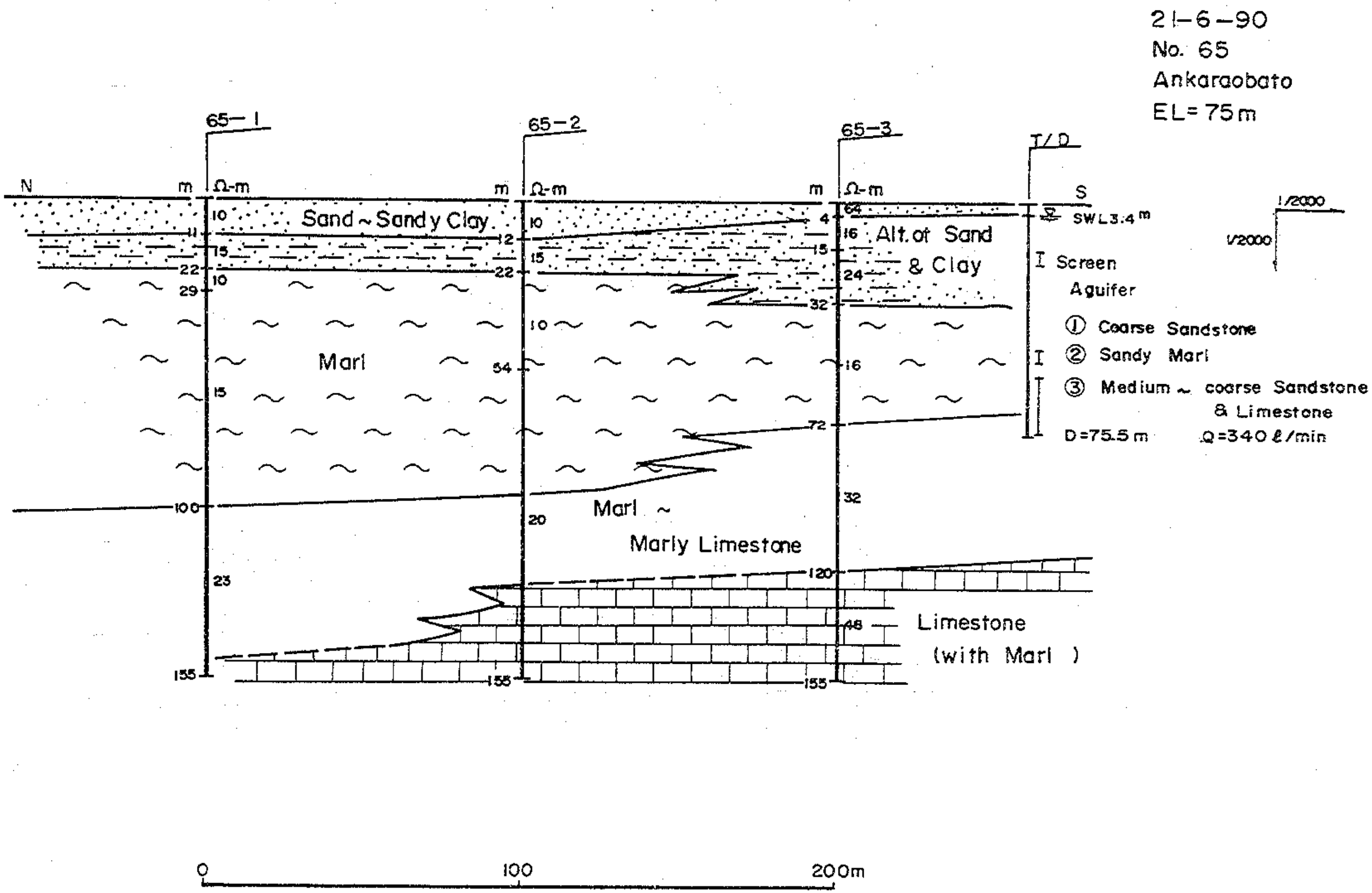


Fig. 3.6.8 Hydrogeological Section of Ankaraobato Area (65)

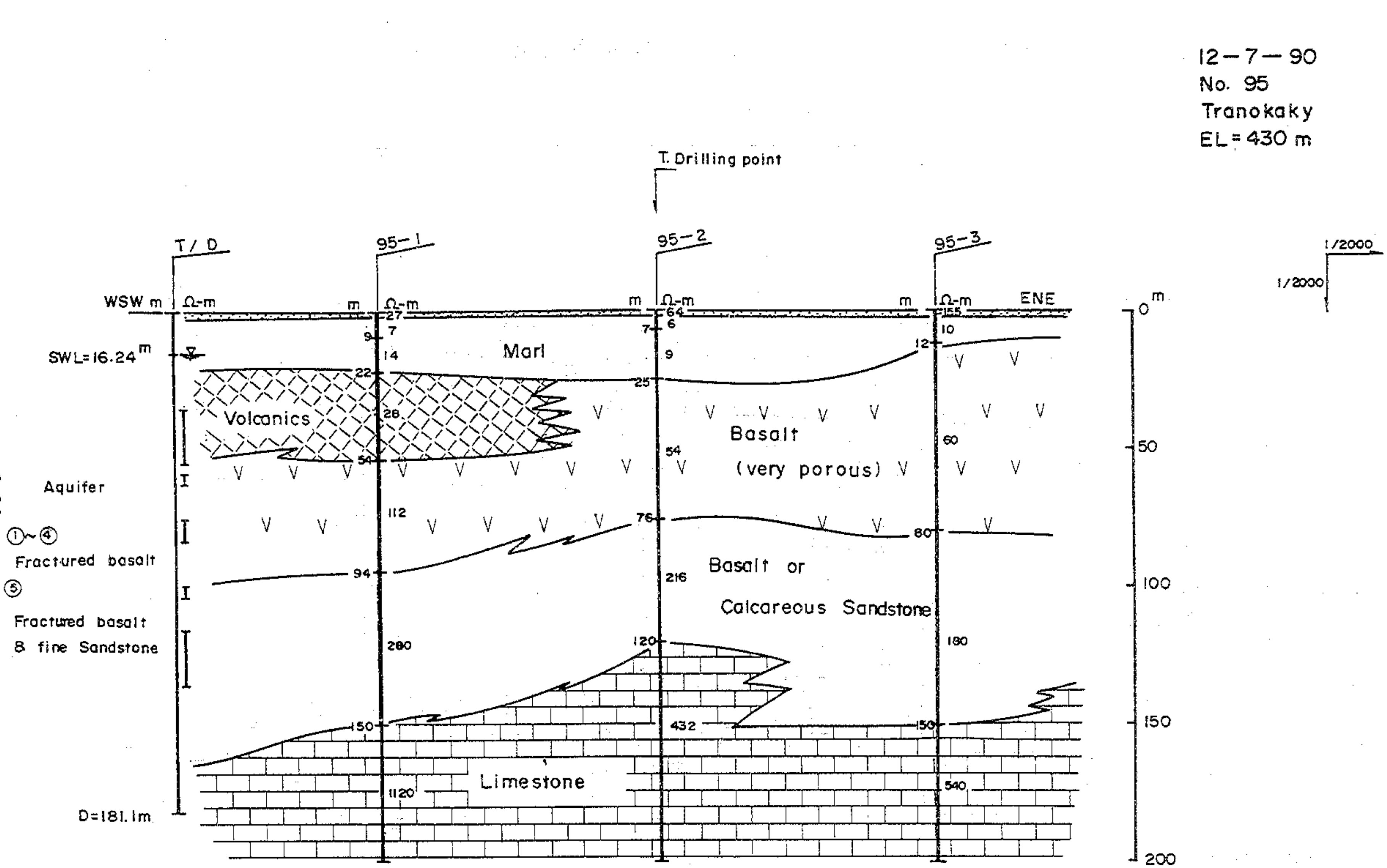


Fig. 3.6.9 Hydrogeological Section of Tranokaky Area (95)

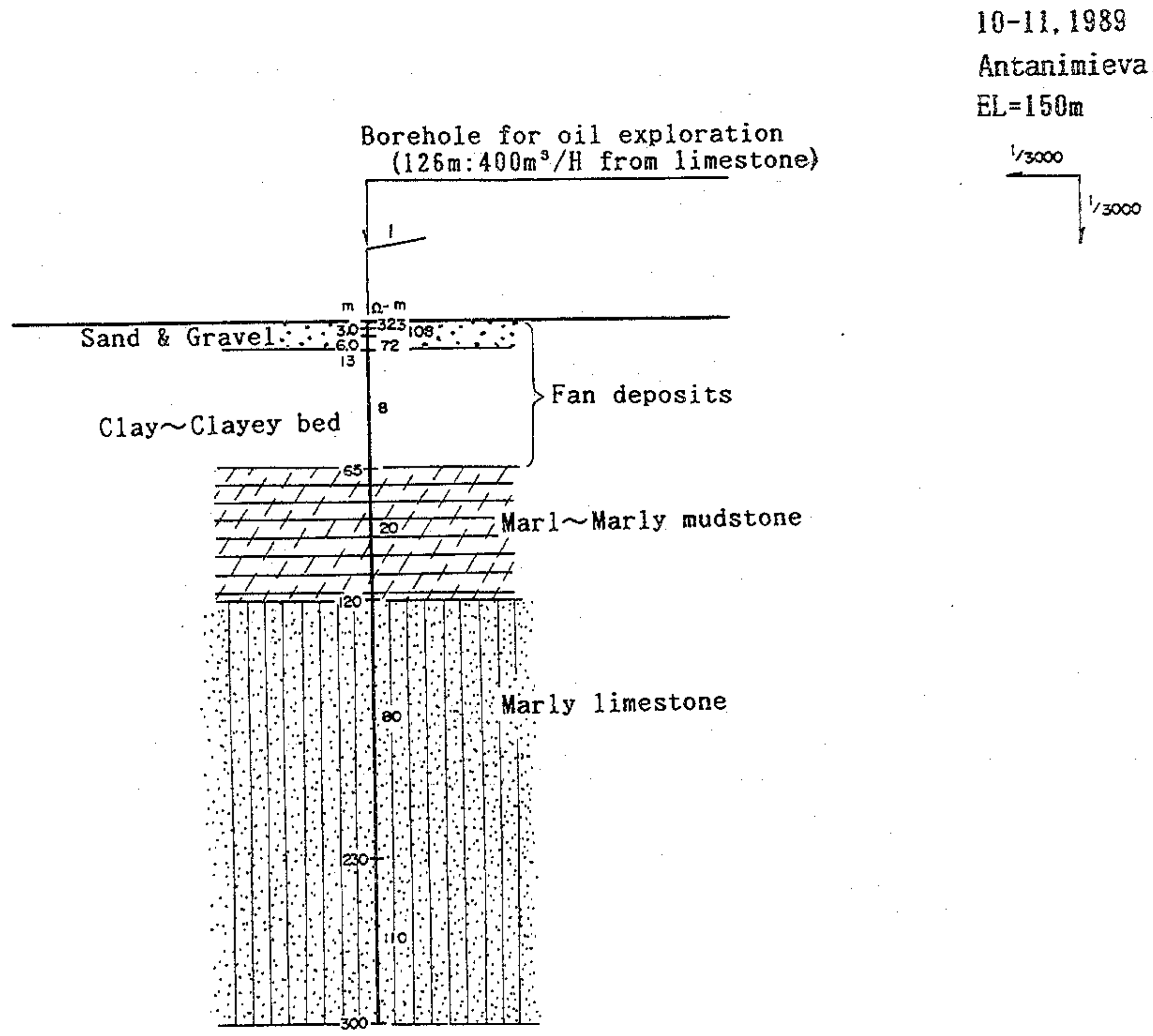


Fig. 3.6.10 Lithological Section of Existing Borehole in Antanimieva

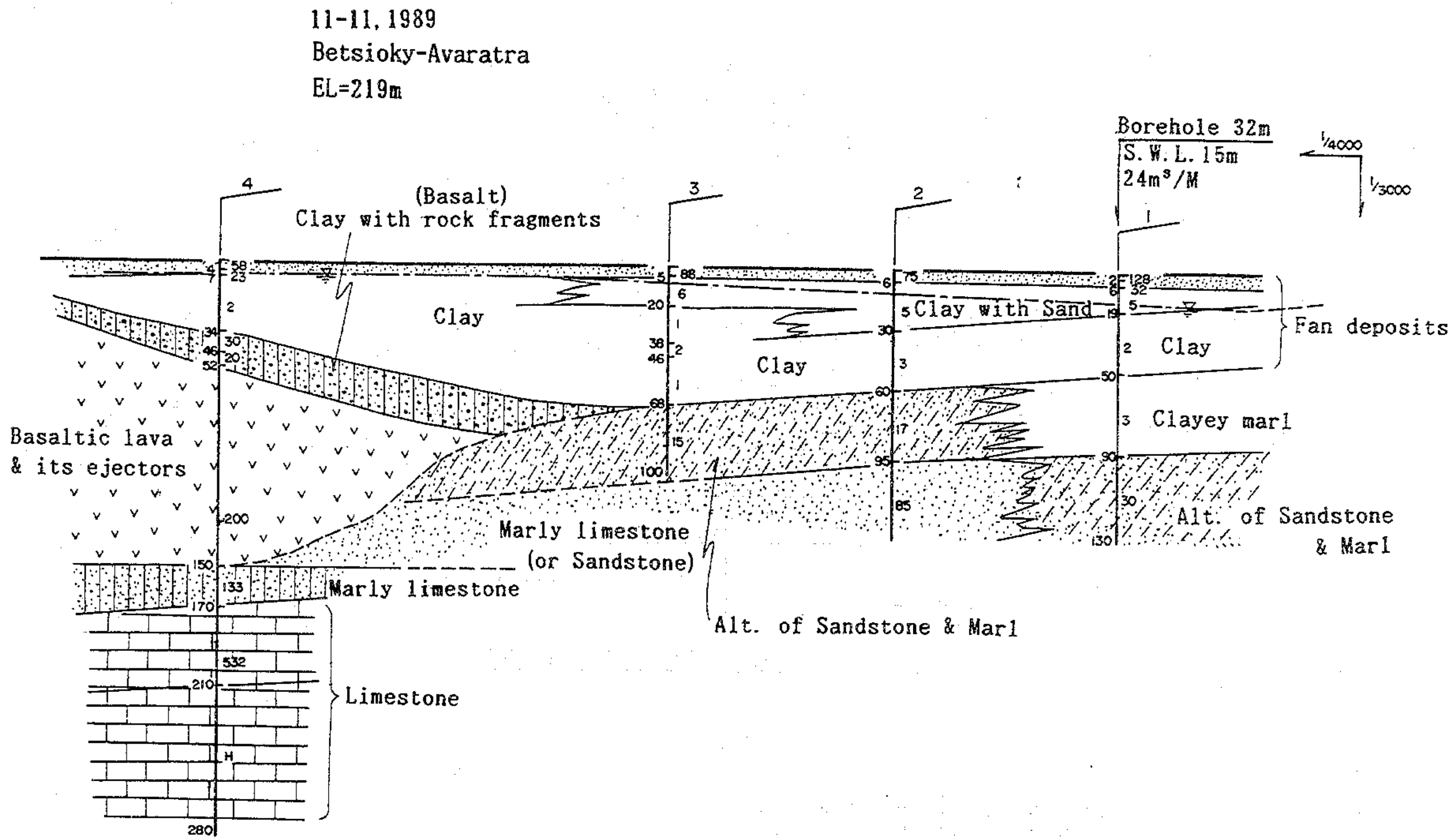


Fig. 3.6.11 Hydrogeological Section of Betsioky Area

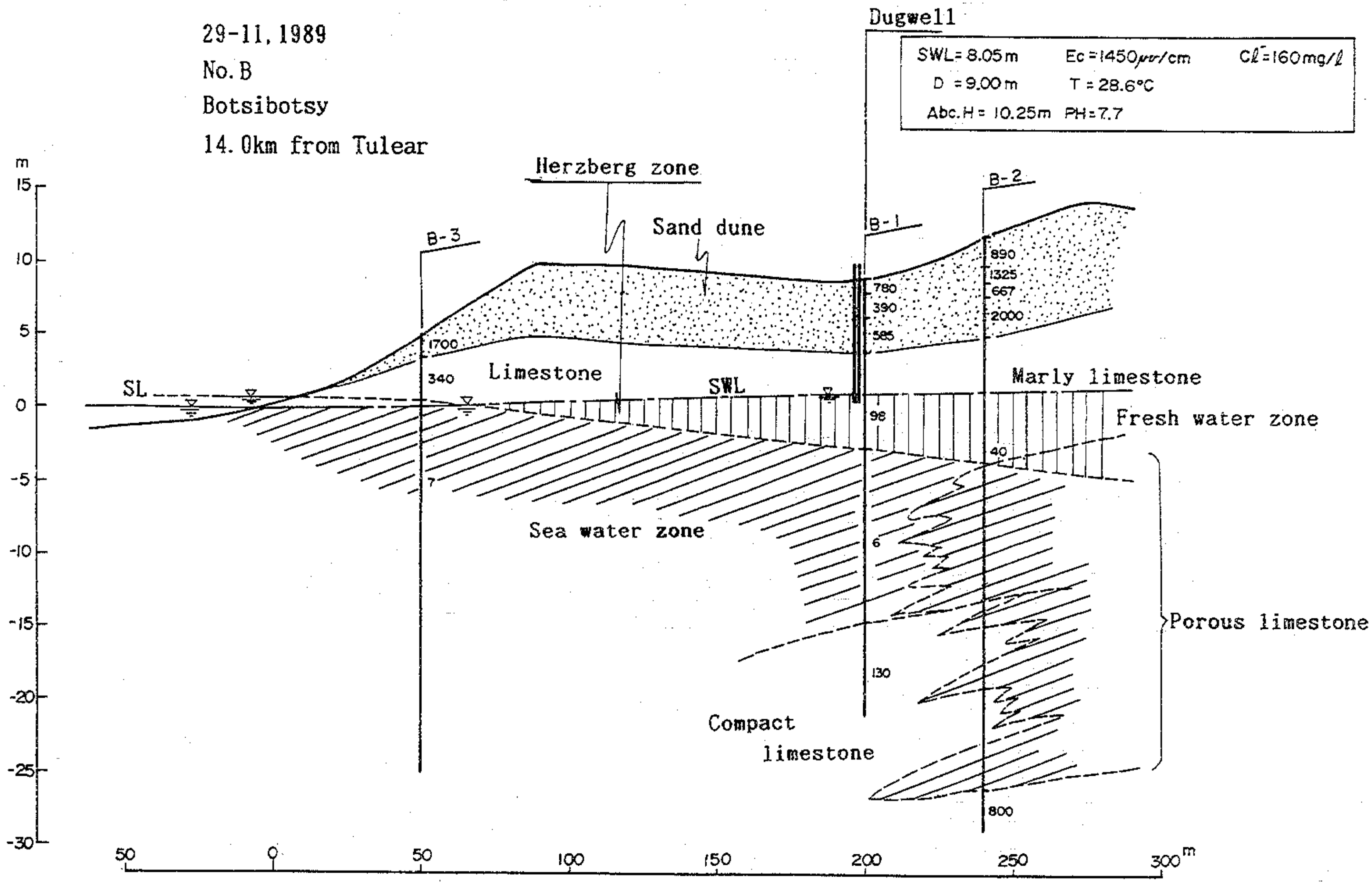


Fig. 3.6.12 Hydrogeological Section of Botsibotsy Area

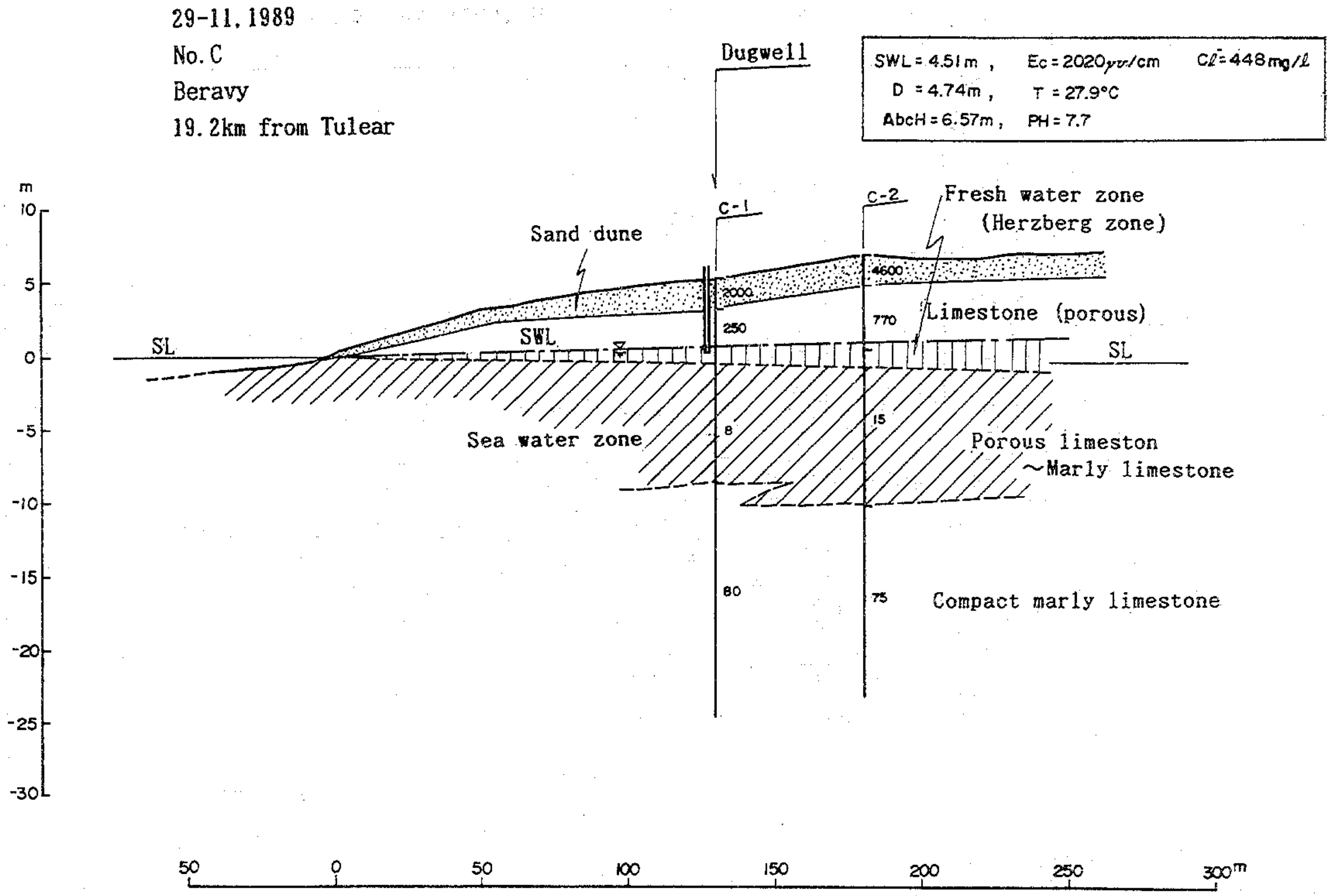


Fig. 3.6.13 Hydrogeological Section of Beravy Area

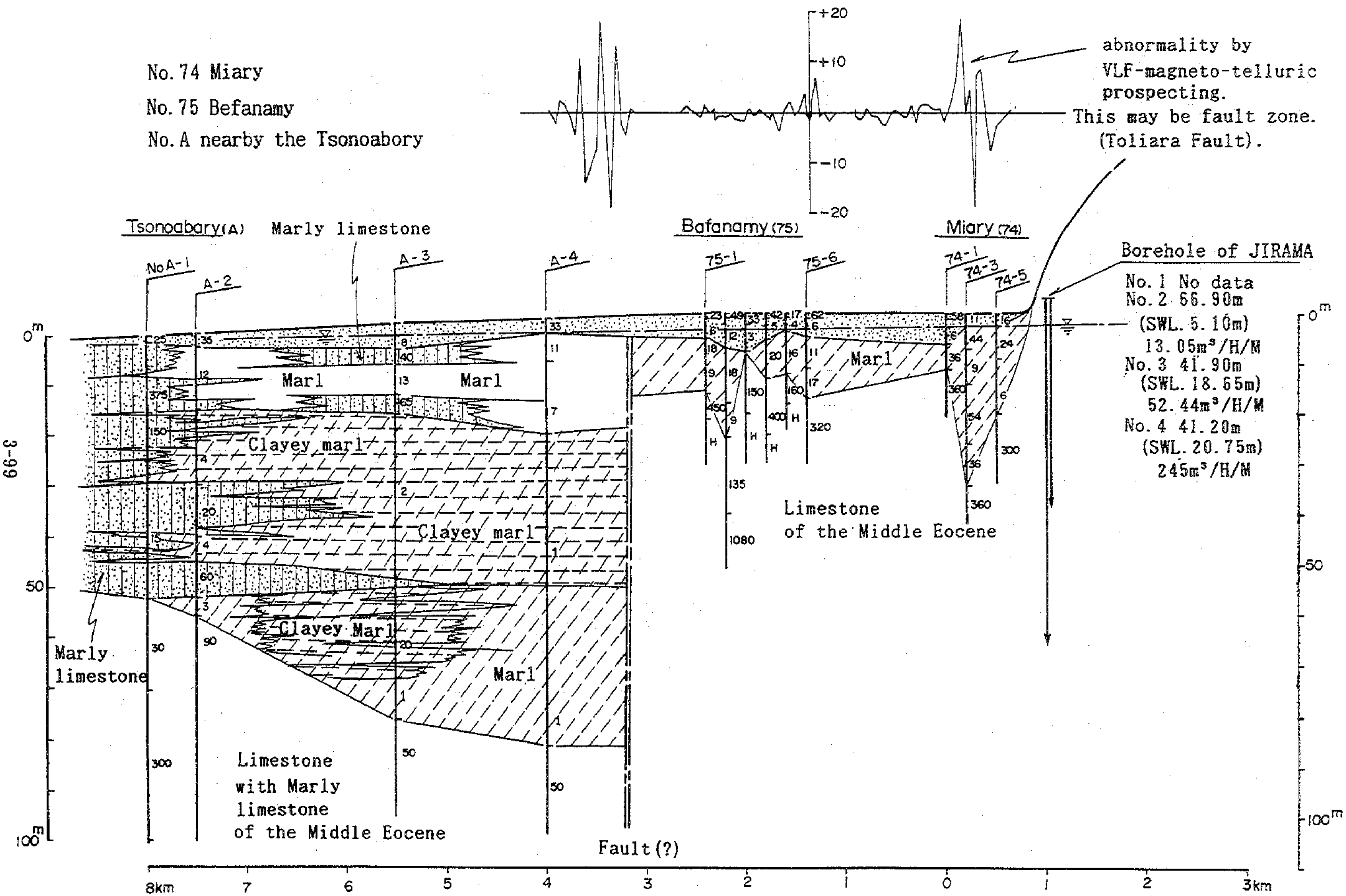


Fig. 3.6.14 Hydrogeological Section of Toliara Plain

3.7 Test Drilling and Pumping Test

As will be discussed in Section 8.3, Phase I work resulted in the selection of 48 potential villages for detailed survey and 8 villages for rehabilitation survey. These villages were selected on the basis of the following criteria: high potential for groundwater availability from the hydrogeological viewpoint, appropriate access road to the village for heavy equipments required for drilling and pumping, pressing community needs for safe water, and the commitment of the community to participate in the operation and maintenance of water supply facilities.

3.7.1 Test Drilling

After completion of the necessary investigations in Phase II, the target sites for test drilling were finally selected, as shown in Fig. 3.7.1, with the following purposes.

a. To investigate the groundwater level and aquifer hydraulic characteristics and to evaluate the over all potential of groundwater resources in the Study Area.

b. To examine the groundwater for suitability as drinking water, and to clarify the groundwater flow mechanism by comparing the chemical components of the groundwater in different regions and in different aquifers.

c. To select the priority areas and to formulate a groundwater development plan for the selected priority areas.

This test drilling survey along with pumping test started on 19 June 1990 and finished on 1st November 1990 as shown in Table 3.7.1. The cumulative drilling depth of 26 test wells was 2,096 m.

The results of the test drillings are summarized in Table 3.7.1 and the detailed drilling records and well logs are presented in Supporting Report(1).

The following major findings were obtained from the test drilling.

a) Befandriana and its surrounding area

Five boreholes with an average depth of 45.5 m were drilled.
The main aquifers in the area consist of medium to coarse grained sandstone and gravelly coarse grained sandstone of the Upper Eocene, and lie between 15 m and 50 m below ground level. The aquifers in the area is highly productive, i.e., the specific capacities of the aquifers are from 23.03 to 304.57 l/min/m.
The quality of the aquifers is good, i.e., the electric conductivity ranges from 141 to 368 µS/cm except for Manoy(22) (EC: 1520 µS/cm).

b) Analatelo(28)

An excellent aquifer consisting of porous limestone of the Upper Eocene was confirmed by the 35m borehole. The specific capacity of the aquifer is 5,016.67 l/min/m, and the groundwater quality is good, i.e., the electric conductivity is 362 µS/cm.

c) Basibasy(27)

The site survey in Phase I confirmed that the groundwater of the old shallow borehole (about 30 m by USAID) was salty and bitter.

The result of this test drilling was, however, not so good in terms of water quantity (Sc: 6.75 l/min/m) and water quality (EC:2.740 µS/cm, a little bitter).
The screen of this borehole was set up between 51.5 m and 79.5 m in the dolomitic marly limestone with a small amount of gypsum.

d) Soahazo(52) to Benetsy(68)

The site survey in Phase I & II confirmed that the groundwater of the old shallow borehole (about 30 m by USAID) and existing dug wells was salty.

The test drilling in this area was, therefore, carefully carried out to clarify the causes of salty taste, and to get more suitable groundwater in terms of quality and quantity.

As shown in Table 3.7.1, the results of test drillings were fairly good when screen position was appropriate, as in Soahazo at 47.1-63.1m below ground level.

The water quality and quantity is generally poor in the aquifer which consists of thin sandstone or marly sandstone (thickness less than 3 m) confined in the thick marl or marly sediment.

e) Ankilimalinika

Ankilimalinika (101) replaced Befanamy(75) which had originally been chosen during Phase I. The water in Befanamy(75) and Miary(74) are supplied by JIRAMA and the inhabitants of these villages are able to get enough water by paying their share of the cost.

There are 3 dug wells and 2 abandoned shallow boreholes by USAID in Ankilimalinika, but the water is very salty, i.e., high electric conductivity of 2,800 to 5,000 μS/cm. Therefore, the people of this village obtain their drinking water from Manombo river, about 5 km from the village.

Thus, one 66m deep borehole was drilled in Ankilimalinika to clarify the realities of the so-called salty taste water. According to the results of test drilling at Benetsy(68) and Ankilimalinika(101), the hydrogeological condition in this area is as shown in Fig.3.7.2. The upper aquifer which is composed of thin sandstone confined by thick marl has a very poor chemical quality of water. On the other hand, the lower aquifer which consists of sandstone with a thickness of more than 3m has generally a better chemical quality of water (Fig.3.7.2).

f) Befoly(78)

This is a representative site of the limestone plateau of the Middle to the Lower Eocene.

The drilling work was commenced by mud drilling method, but it was changed to air hammer drilling method at 50.50 m due to the frequently lost circulations. By the air hammer method, the drilling work was speeded up from several meters per day to 20-50 m per day. The drilling work of this borehole was stopped at 202 m below the ground level because of the limited lifting power of the drilling machine. The groundwater level was confirmed to be at 178.56 m below the ground level.

The discharge rate from this borehole was only 10 l/min. Therefore, after installing a 6" casing in this borehole, additional drilling work was carried out by air drilling method using 5 5/8" tricone bit without drill collar. The drilling depth could go no further than 226.5 m, restricted by the availability of drilling rod. However, one part of fissured limestone was found at 224.5 m below the ground level. This aquifer has a capacity of 110 l/min and electric conductivity of 403 µS/cm.

As a conclusion, it is strongly recommended to drill a borehole of more than 250 m for groundwater development in this area of limestone plateau.

g) Tranokaky(95)

A 181 m borehole was drilled to investigate the hydrogeological conditions and the availability of groundwater in this area which geologically is composed of the Lower to Upper Cretaceous formation with basaltic rocks.

According to drilling results, the main aquifer in this area is partially fractured basaltic rocks with a thickness of about 125 m, discharge rate of 110 l/min and electric conductivity of 894 µS/cm. An impermeable layer of dark black shale or mudstone is found between 150 m and 181 m below the ground level.

h) Maninday(88) and Analamary(96)

Two boreholes were drilled to investigate the hydrogeological features and the availability of groundwater in the area which geologically is composed of the Lower Jurassic continental deposits (Isalo II).

As shown in well logs in detail, lithofacies of aquifer in this area consist mainly of reddish brown or white gray coarse grained sandstone rich in quartz grains. Pumping discharges were 480 l/min (specific capacity 43.95 l/min/m) in Maninday and 720 l/min (specific capacity 41.76 l/min/m) in Analamary.

The aquifer of Isalo II formation is generally highly productive and the water quality is good (EC: 106 to 142 µS/cm).

i) Tandrano(34)

A 150.1 m borehole was drilled to investigate the hydrogeological features and the availability of groundwater in the area which geologically is composed of the Middle Jurassic continental deposits (Isalo III_2). According to the drilling results, lithofacies of aquifer in this area consist mainly of brown or brownish gray fine to medium-grained sandstone.

Pumping discharge was 660 l/min (specific capacity 41.67 l/min/m) and the productivity of the aquifer is similar to that of the aquifer of Isalo II formation in terms of water quantity and quality.

j) Berenty-Betsileo(46)

The main water source of Berenty-Betsileo is Isahena river. According to the results of hydrogeological investigations in Phase I, Berenty-Betsileo(46) and its surrounding area is geologically composed of the neritic sediments with calcareous deposits such as marl and marly fine grained or silty sandstone. The groundwater was evaluated to be generally poor in terms of quantity and quality.

The test drilling at Berenty-Betsileo was mainly carried out to confirm the above mentioned poor groundwater condition. The drilling results are described below, and the water quality is not so suitable for drinking.

- Lithofacies of aquifer : marl or marly fine to medium grained sandstone.
- Pumping discharge : 60 l/min (S/C 0.67 l/min/m)
- Electric conductivity : 2190 µS/cm (Cl: 248 mg/l)
- pH : 8.4

3.7.2 Pumping Test

As for the pumping test, the step drawdown, the constant rate and the recovery tests were carried out at 25 drilled boreholes using two submersible motor pumps in order to estimate aquifer properties.

The number of steps, the duration of pumping, and other pumping conditions were as follows:

a) Step drawdown test

In principle, five(5) step drawdown tests were carried out in order to determine the optimum discharge, formation loss and well loss of a single well. During the test, the pumping rate was increased in five(5) steps at regular intervals. This pumping rate at each interval was determined based on the results of the preliminary pumping test. The pumping duration during each step was 2-3 hours.

b) Constant rate test

This test was carried out after the step drawdown test, when the water level recovered to nearly the original static level. The constant pumping rate was determined from the results of the step drawdown test. The pumping duration was forty eight(48) hours in principle.

c) Recovery test

Recovery time measurement was carried out at regular intervals for twenty four(24) hours, in principle, after constant rate pumping was stopped.

In addition to the normal pumping tests at the boreholes mentioned above, air lift pumping test was carried out as a part of well development work. The duration of air lifting was about twenty four(24) hours.

Time drawdown and time recovery measurements were plotted on log and semi-log graph paper in order to calculate transmissivity, permeability, and storage coefficients.
Methods of analysis used in this study were Theis and Jacob, which are applicable to confined aquifers in un-

steady state conditions.

The detailed results of pumping tests are given in Data Book and summarized aquifer parameters are shown in Table 3.7.1. The main aquifer properties in the Study Area are described by different regions and by different aquifers in the next sub-section, based on the results of this pumping test.

3.7.3 Aquifer Properties

The major aquifer hydraulic characteristics that affect groundwater movement and groundwater development potential are the ability to transmit water and the ability to yield water from storage. These characteristics are called transmissivity, storativity and specific capacity, respectively, and are established by pumping test.

Specific capacity is the amount of yield divided by drawdown, and is closely related to transmissivity.

Empirically, transmissivity is given by :

$$T = a\ Q/s = a\ S_c$$

where,

T = Transmissivity (m2/min)
S_c = Specific capacity (l/min/m)
s = Drawdown in the borehole (m)
Q = Yield of the borehole (l/min)
a = Dimensionless constant (based on field experience, Logan (1964) suggested a = 1.22)

The results of pumping test on the newly drilled boreholes in this study are given in Table 3.7.1. The main aquifer properties in the study area are summarized by region and by aquifer type as follows.

(1) Lower Jurassic continental deposits (Isalo II)

In this area, 2 boreholes were drilled in Maninday(88) and Analamary(96). The aquifers at drilling sites are mainly composed of coarse-grained sandstone rich in quartz grains, and thin medium to fine grained sandstone or gravelly sandstone.

The following results for aquifer constants were obtained by pumping test.

	Maninday(88)	Analamary(96)
Specific capacity (l/min/m)	43.53	41.76
Trasmissivity (m^2/min)		
. Theis	5.97×10^{-2}	5.16×10^{-2}
. Jacob	8.23×10^{-2}	5.6×10^{-2}
. Recovery	5.22×10^{-2}	3.92×10^{-2}

According to the results of the pumping tests and hydrogeological investigations, the aquifer in the lower Jurassic continental deposits (Isalo II) is evaluated in general as highly productive. Expected maximum pumping discharge ranges from 480 l/min in Maninday to 720 l/min in Analamary.

(2) Lower Jurassic neritic sediments (Isalo II)

The Isalo II formation at Berenty-Betsileo 46 and its surrounding area consists mainly of neritic sediments which is composed of marl, marly sandstone, sandymarl, fine-grained sandstone and silty sandstone, and the water quality of shallow groundwater is poor due to its salty taste.

Therefore, a 140 m borehole was drilled to investigate the aquifer properties in the deeper portion of about 100 m below the ground level. However, the results of this test drilling were not as expected in terms of quantity and quality, as shown below.

Specific capacity	1.53 l/min/m
Transmissivity	
. Theis	2.76×10^{-3} m^2/min
. Jacob	3.55×10^{-3}
. Recovery	3.27×10^{-3}
(E/C : 2190 μs/cm, Cl : 248 mg/l, PH : 8.4)	

(3) Middle Jurassic continental deposits (Isalo III)

In this area, a 150 m borehole was drilled in Tandrano(34). The main aquifers at the drilling site are composed of fine to medium grained sandstone and fine grained sandstone with thin silty sandstone. The following results for aquifer constants were obtained by pumping test.

Specific capacity	41.67 l/min/m
Trasmissivity	
. Theis	8.46×10^{-2} m^2/min
. Jacob	8.45×10^{-2}
. Recovery	6.80×10^{-2}

The aquifer constants in the Middle Jurassic continental deposits (Isalo 2 III) are similar to those of the lower Jurassic continental deposits (Isalo II), and the aquifer is evaluated to be in general highly productive. The maximum pumping discharge was 660 l/min.

(4) Lower to Upper Cretaceous formation with basaltic rocks

In this area, a 181 m borehole was drilled in Tranokaky 95. The main aquifer at the drilling site is composed of partially fractured basaltic rocks with a thickness of about 125 m. The results of pumping test were as follows.

Specific capacity	11.65 l/min/m
Transmissivity	
. Theis	8.88×10^{-3} m^2/min
. Jacob	5.05×10^{-3}
. Recovery	8.04×10^{-3}
Max pumping discharge	110 l/min

From the results of this test drilling and regional hydrogeologic investigations, the aquifer of basaltic rocks is evaluated to be in general moderately productive.

This test drilling did not produce any information on the aquifer composed of sandstone of the Cretaceous, which theoretically should be highly productive.

(5) Limestone of the Lower Eocene

In this limestone area, a 226.5 m borehole was drilled in Befoly(78) to investigate the aquifer properties of limestone of the Lower Eocene. As described above, the aquifer constants of the limestone was not obtained from the results of this test drilling due to the limited capacity of the drilling machine and drilling tools.

However, the aquifer constants of limestone of the Middle to Upper Eocene were obtained from the results of test drilling elsewhere in this study. In addition, hydrogeological investigations show similarities between the lithofacies of the limestone of the Lower Eocene and the limestone of the Middle to Upper Eocene.

The aquifer constants of limestone of the Lower Eocene are, therefore, expected to be mostly similar to those of the limestone of the Middle to Upper Eocene.

	Specific capacity (l/min/m)	Pump discharge (l/min)	Drawdown (m)
Analatelo(28)	5,016.67	301	0.06
Manombo(63)	423.08	165	0.39
Manoroka(81)	-	158	0.00
JIRAMA No.2	217.50		
in No.3	874.00		
Miary No.4	4,083.33		

(6) Neritic sediments of the Middle to Upper Eocene

According to the results of test drilling and hydrogeological investigations, the western lowland region of the Study Area is mainly composed of alternation of the neritic sedi ments such as limestone, marly limestone, marl, sandy marl, marly sandstone and fine to coarse grained sandstone.

The good aquifer, in which the specific capacity is more than 40 l/min/m, is generally composed of limestone, marly limestone and medium to coarse grained sandstone with a thickness of more than 3 m. On the other hand, the aquifer which consists of sandy marl, marly sandstone and thin sandstone confined in thick marl is generally of low to moderate productivity in terms of quantity and quality.

The specific capacity of the aquifers in this region ranges from 3.71 l/min/m in Analamisampy 53 to 5,016 l/min/m in Analatelo 28, and the aquifers in this region are generally highly productive as shown in Table 3.7.2.

Table 3.7.1 Results of Test Drilling and Pumping Test (1)

Well No. & Location	Results of Test Drilling: Drilling Rig	Started / Completed	Drilled Depth m	S.W.L. (GL-m)	Screen Position (GL-m)	Lithofacies of Aquifer	Results of Pumping Test: Discharge (Q) l/min.	Drawdown (S) m	Specific capacity l/min./m	Transmissivity m²/min.: Theis	Jacob	Recovery	Water Quality: Electric Conductivity µs/cm	Cl mg/l	pH
22 Manoy	SANKYO SM-200	25.08.90 31.08.90	42.0	8.37	① 18.4~ 38.4 (4")	① medium~coarse sandstone & small gravelly sandstone	280 (~309)	12.16	23.03	4.46×10^{-2}	4.34×10^{-2}	9.32×10^{-2}	1,520	286	7.1
23 Ampoza	SANKYO SM-200	18.08.90 24.08.90	50.0	5.28	① 15.5~ 23.5 (4") ② 31.5~ 47.5 (4")	① medium sandstone ② medium~coarse sandstone	283 (~310)	9.92	28.53	4.69×10^{-2}	4.71×10^{-2}	8.38×10^{-2}	368	12	7.3
25 Sihanaka	SANKYO SM-200	01.09.90 06.09.90	41.0	5.74	① 19.5~ 39.5 (4")	① medium~coarse sandstone	300 (~307)	1.86	161.29	3.62×10^{-1}	4.32×10^{-1}	3.33×10^{-1}	310	11	7.5
27 Basibasy	SANKYO SM-200	29.09.90 06.10.90	83.0	14.49	① 51.5~ 79.5 (4")	① sandy marl & limestone	201 (~222)	29.78	6.75	8.89×10^{-3}	9.76×10^{-3}	1.47×10^{-2}	2,740	720	6.8
28 Analatelo	SANKYO SM-200	14.09.90 01.10.90	35.0	3.18	① 11.5~ 31.5 (4")	① alternation of sandy marl, sandy limestone & limestone	301 (~321)	0.06	5,016.67	-	-	-	362	12	7.4
29 Mangotroka	SANKYO SM-200	07.09.90 13.09.90	41.0	3.57	① 14.5~ 38.5 (4")	① medium~coarse sandstone	336	1.72	195.35	-	1.14×10^{-0}	1.31×10^{-0}	141	12	7.0
52 Soahazo 52-1	SANKYO SM-200	03.07.90 12.07.90	76.0	36.17	① 47.1~ 63.1 (4")	① sandy marl	130 (~293)	1.08	120.37	-	1.13×10^{-0}	8.20×10^{-1}	1,080	70	7.3
52 Soahazo 52-2	SANKYO SM-200	13.07.90 17.07.90	34.0	4.90	① 7.1~ 15.1 (4") ② 23.1~ 27.1 (4")	① medium~coarse sandstone ② sandy marl	167	5.72	29.20	4.12×10^{-2}	4.69×10^{-2}	7.25×10^{-2}	3,630	252	7.4
53 Analamisampy	SANKYO SM-200	18.07.90 25.07.90	71.0	13.11	① 7.5~ 11.5 (4") ② 31.5~ 35.5 (4") ③ 43.5~ 47.5 (4") ④ 51.5~ 55.5 (4") ⑤ 59.5~ 67.5 (4")	① sandy limestone ②, ④ medium sandstone & sandy marl ③ sandstone ⑤ sandy marl	30 (~112)	8.09	3.71	3.18×10^{-3}	3.20×10^{-3}	6.84×10^{-3}	1,350	206	7.2
54 Belitsaka	SANKYO SM-200	26.07.90 31.07.90	66.0	12.78	① 31.5~ 47.5 (4") ② 55.5~ 59.5 (4")	① medium sandstone & sandy marl ② coarse sandstone	200 (~270)	14.70	13.61	1.08×10^{-2}	1.08×10^{-2}	8.65×10^{-3}	2,080	444	7.0
55 Ampasikibo	SANKYO SM-200	01.08.90 06.08.90	50.0	9.16	① 23.5~ 43.5 (4")	① sandy marl	280 (~287)	6.96	40.23	1.30×10^{-1}	8.71×10^{-2}	1.22×10^{-1}	817	22	7.2
56 Namaboha	SANKYO SM-200	07.08.90 15.08.90	83.0	16.50	① 39.5~ 47.5 (4") ② 63.5~ 73.5 (4")	① medium~coarse sandstone ② sandy marl & sandy limestone	247 (~268)	16.67	14.82	3.17×10^{-2}	3.10×10^{-2}	6.43×10^{-2}	975	95	7.3
59 Ampihamy	SANKYO SM-200	07.10.90 14.10.90	53.0	8.30	① 23.5~ 51.5 (4")	① medium~coarse sandstone	296 (~315)	7.03	42.11	-	3.45×10^{-1}	5.64×10^{-1}	996	86	7.2
65 Ankaraobato	SANKYO SM-200	24.06.90 02.07.90	75.5	3.40	① 15.2~ 19.2 (4") ② 47.2~ 51.2 (4") ③ 55.2~ 75.2 (4")	① coarse sandstone ② sandy marl ③ medium~coarse sandstone & limestone	339 (~361)	2.93	115.70	1.49×10^{-1}	1.67×10^{-1}	1.46×10^{-1}	849	62	7.2
— Befandriana	SANKYO SM-200	19.09.90 22.09.90	53.0	12.30	① 18.0~ 26.0 (6") ② 33.0~ 38.0 (6")	①, ② medium~coarse sandstone	300	0.985	304.57	6.28×10^{-1}	6.54×10^{-1}	5.38×10^{-1}	565	16	7.1
63 Manombo-Atm	KOKEN	26.09.90 30.09.90	27.0	4.53	① 11.5~ 23.5 (6")	① 11.5~19.0 medium~coarse sandstone 19.0~21.0 gravelly sandstone 23.0~23.5 fissured limestone	165 (~263)	0.39	423.08	-	-	2.36×10^{-0}	1.000	62	7.2
67 Tsefanoka	KOKEN	08.10.90 12.10.90	45.0	24.30	① 22.0~ 42.0 (4")	① 23~28 marly limestone 28~36 coarse sandstone 36~42 limestone ≫ sandstone	142 (~144)	3.05	46.56	1.23×10^{-1}	1.18×10^{-1}	2.17×10^{-1}	602	10	7.4
68 Benetsy	KOKEN	01.10.90 06.10.90	72.0	13.51	① 39.5~ 43.5 (6") ② 47.5~ 51.5 (6") ③ 59.5~ 67.5 (6")	①, ②, ③ brown coarse sandstone with thine marly sandstone	158 (~161)	2.015	78.41	-	2.33×10^{-1}	1.65×10^{-1}	977	58	7.4
101 Ankilimalinika	KOKEN	22.10.90 28.10.90	66.0	14.35	① 42.0~ 62.0 (4")	① 42~47 sandy marl 47~52 coarse sandstone 58~60 coarse sandstone with thine marl	152 (~155)	1.67	91.02	-	3.02×10^{-1}	2.38×10^{-1}	2,458	134	7.5
81 Manoroka	KOKEN	15.10.90 20.10.90	58.0	5.23	① 30.0~ 50.0 (4")	① 30~37 coarse sandstone 37~40 porous limestone 40~43 coarse sandstone 43~50 fissured limestone	158	0.000	-	-	-	-	1,210	95	7.4

Table 3.7.1 Results of Test Drilling and Pumping Test (2)

Well No. & Location	Results of Test Drilling: Drilling Rig	Started / Com-pleted	Drilled Depth m	S. W. L. (GL-m)	Screen Position (GL-m)	Lithofacies of Aquifer	Results of Pumping Test: Discharge (Q) l/min.	Drawdown (S) m	Specific capacity l/min./m	Transmissivity m²/min.: Theis	Jacob	Recovery	Water Quality: Electric Conductivity μs/cm	Cl mg/l	pH
78 Befoly	TONE TOP-200	19. 06. 90 / 15. 09. 90	226. 5	178. 56	①183. 5~195. 5 (6") ②224. 5~226. 5 open hole (5⁵/₈")	Porous & fissured limestone ① 10l/min., ②100l/min.	(air lifting) 110	–	–	–	–	–	403	14	7. 8
95 Tranokaky	TONE TOP-200	14. 07. 90 / 23. 07. 90	181. 1	16. 57	① 35. 5~ 55. 5 (6") ② 59. 5~ 63. 5 (6") ③ 75. 5~ 83. 5 (6") ④ 99. 5~103. 5 (6") ⑤115. 5~135. 5 (6")	①~④ fractured basalt (C-3) ⑤ fractured basalt & fine sandstone	38. 7(~110)	3. 32	11. 65	8.88×10^{-3}	5.05×10^{-3}	8.04×10^{-3}	894	62	7. 5
34 Tandrano	TONE TOP-200	16. 08. 90 / 28. 08. 90	150. 1	32. 72	① 35. 5~ 39. 5 (6") ② 99. 5~103. 5 (6") ③107. 5~119. 5 (6") ④135. 5~139. 5 (6")	① fine to medium sandstone (III) ②, ③ fine sandstone ④ fine sandstone & silty sandstone	300(~650)	7. 20	41. 67	8.46×10^{-2}	8.45×10^{-2}	6.86×10^{-2}	410	16	7. 4
46 Berenty-Betsileo	TONE TOP-200	29. 08. 90 / 07. 09. 90	140. 0	15. 54	① 39. 5~ 43. 5 (6") ② 59. 5~ 63. 5 (6") ③ 71. 5~ 75. 5 (6") ④ 79. 5~ 91. 5 (6") ⑤107. 5~111. 5 (6") ⑥127. 5~131. 5 (6")	① marl to marly sandstone ②, ③ fine sandstone (with medium s. s.) ④ silty sandstone & sandy marl ⑤ silty sandstone ⑥ marly sandstone (II)	68(~ 80)	44. 45	1. 53	2.76×10^{-3}	3.55×10^{-3}	3.27×10^{-3}	2, 190	248	8. 4
88 Maninday	TONE TOP-200	25. 07. 90 / 31. 07. 90	73. 5	16. 29	① 15. 5~ 31. 5 (6") ② 35. 5~ 43. 5 (6") ③ 51. 5~ 55. 5 (6")	① weathered coarse sandstone & gravelly sandstone (II) ②, ③ weathered coarse sandstone	360(~480)	8. 27	43. 53	5.97×10^{-2}	8.23×10^{-2}	5.26×10^{-2}	106	10	6. 9
96 Analamary	TONE TOP-200	01. 08. 90 / 10. 08. 90	204. 0	35. 00	① 31. 5~ 39. 5 (6") ② 51. 5~ 55. 5 (6") ③ 59. 5~ 75. 5 (6") ④135. 5~139. 5 (6") ⑤163. 5~167. 5 (6")	① weathered coarse sandstone ②~④ coarse sandstone ⑤ coarse sandstone with fine sandstone beds (Isalo II F.)	360(~600)	8. 62	41. 76	5.16×10^{-2}	5.06×10^{-2}	3.92×10^{-2}	142	8	6. 4

Table 3.7.2 Main Aquifer Properties

Aquifer		Specific capacity (l/min./m)	Transmissivity (m^2/min.)			Remarks
			Theis	Jacob	Recovery	
Neritic sediments of the Middle to Upper Eocene	Befandriana area	6.75-304.57 (119.92)	8.89×10^{-3}-6.28×10^{-1} (2.18×10^{-1})	9.76×10^{-3}-6.54×10^{-1} (3.88×10^{-1})	1.47×10^{-2}-5.38×10^{-1} (3.95×10^{-1})	Except Analatelo (28)
	Soahazo area	13.61-120.37 (43.39)	1.08×10^{-2}-1.30×10^{-1} (5.34×10^{-2})	1.08×10^{-2}-1.13×10^{0} (2.75×10^{-1})	8.65×10^{-3}-8.20×10^{-1} (2.75×10^{-1})	Except Analamisampy (53)
	Benetsy area	46.56-115.70 (82.92)	1.23×10^{-1}-1.49×10^{-1} (1.36×10^{-1})	1.18×10^{-1}-3.02×10^{-1} (2.05×10^{-1})	1.46×10^{-1}-2.38×10^{-1} (1.92×10^{-1})	
Limestone of the Lower to Middle Eocene		217.50-5016.67 (2122.92)	—	—	2.36×10^{0} -	※1 T(av.): 2.59×10^{0} m^2/min.
Basaltic rocks of the Upper Cretaceous		11.65	8.88×10^{-3}	5.05×10^{-3}	8.04×10^{-3}	
Continental deposits of the Middle Jurassic		41.67	8.46×10^{-2}	8.45×10^{-2}	6.86×10^{-2}	Isalo² Ⅲ F.
Continental deposits of the Lower Jurassic		41.76- 43.53 (42.65)	5.06×10^{-2}-5.97×10^{-2} (5.57×10^{-2})	5.16×10^{-2}-8.23×10^{-2} (6.65×10^{-2})	3.92×10^{-2}-5.26×10^{-2} (4.59×10^{-2})	Isalo Ⅱ F. Except Berenty (46)

(   ) : Average value

※1 : Estimated value from the borehole records of Analatelo (28), Manombo (63) and Miary No2 to No4 of JIRAMA.

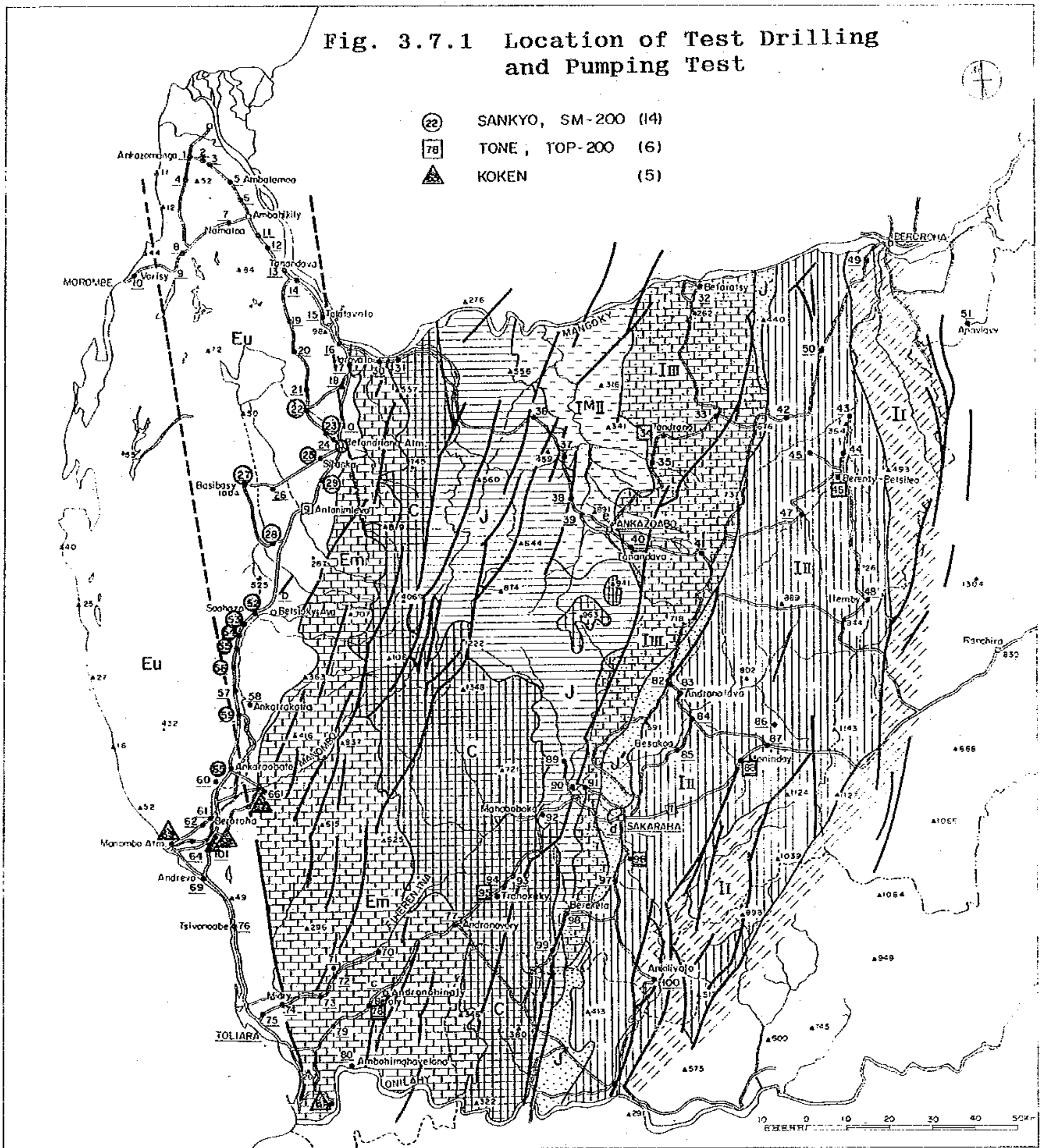


Fig. 3.7.1 Location of Test Drilling and Pumping Test

No Villages

I. Fiv. MOROMBE

1 Ankazoanga
2 Beadabo
3 befasy
4 Ankilifolo(1)
5 Ambalamoa
6 Tsianihy
7 Namatoa
8 Mangolovolo
9 Ankida
10 Vorisy
11 Andranomanitsy
12 Berantala
13 Tanandava
14 Antsakoabe
15 Talatavalo
16 Ambiky
17 Marovato
18 Andranoboka
19 Satrambondro
20 Mahavozokely
21 Antranosatra
22 Manoy
23 Ampoza
24 Ankilifolo(2)
25 Sihanaka
26 Bemoka
27 Basibasy
28 Analatelo
29 Mangotroka
30 Nosy-Ambositra
31 Tsiarimpioke

II. Fiv. ANKAZOABO ATM

32 Betaratsy
33 Andranomanintsy
34 Tandrano
35 Ampandramitsetaky
36 Andranomafana
37 Manakiala
38 Berenty-Ankilimasy
39 Betsinefo
40 Tanandava
41 Ampoza
42 Ipetsa Alo
43 Nandabe Atm
44 Soatanimbary
45 Sahanory Atn
46 Berenty-Betsileo
47 Ankilivalokely
48 Ifeaby

III. Fiv. BERORDHA

49 Tanandava-Antaifasy
50 Anjamitikitra
51 Anaviavy

IV. Fiv. TOLIARA I / II

52 Soahazo
53 Analamisampy
54 Belitsaka
55 Ampasikibo
56 Namaboha
57 Antseva
58 Ankilimlavoloka
59 Ampihamy
60 Ambondro
61 Beroroha
62 Antsomarify
63 Manombo-Atm
64 Antandroka
65 Ankaraobato
66 Andoharano
67 Tsefanoka
68 Benetsy
69 Andrevo
70 Anjamala
71 Ampihalia
72 Behompy
73 Ambolonkira
74 miary
75 Befanamy
76 Tsivonoabe
77 Andranovory
78 Befoly
79 Ankororoka
80 Ambohimahavelona
81 Manoroka
101 Ankilimalinika

V. Fiv. SAKARAHA

82 Iaborana
83 Andranolava
84 Lambomakandro
85 Besakoa(1)
86 Besakoa(2)
87 Ampandra
88 Maninday
89 Bevoalavo
90 Tanambao
91 Ambahimalitsy
92 Mahaboboka
93 Mahasoa
94 Andamasiny-Vinete
95 Iranokaky
96 Analamary
97 Antanimora
98 Bereketa
99 Ankilimitraloka
100 Ankilivalo

a Befandriana
b Betsioky Nord
c Andranohinaly
d Sakaraha
e Ankazoabo

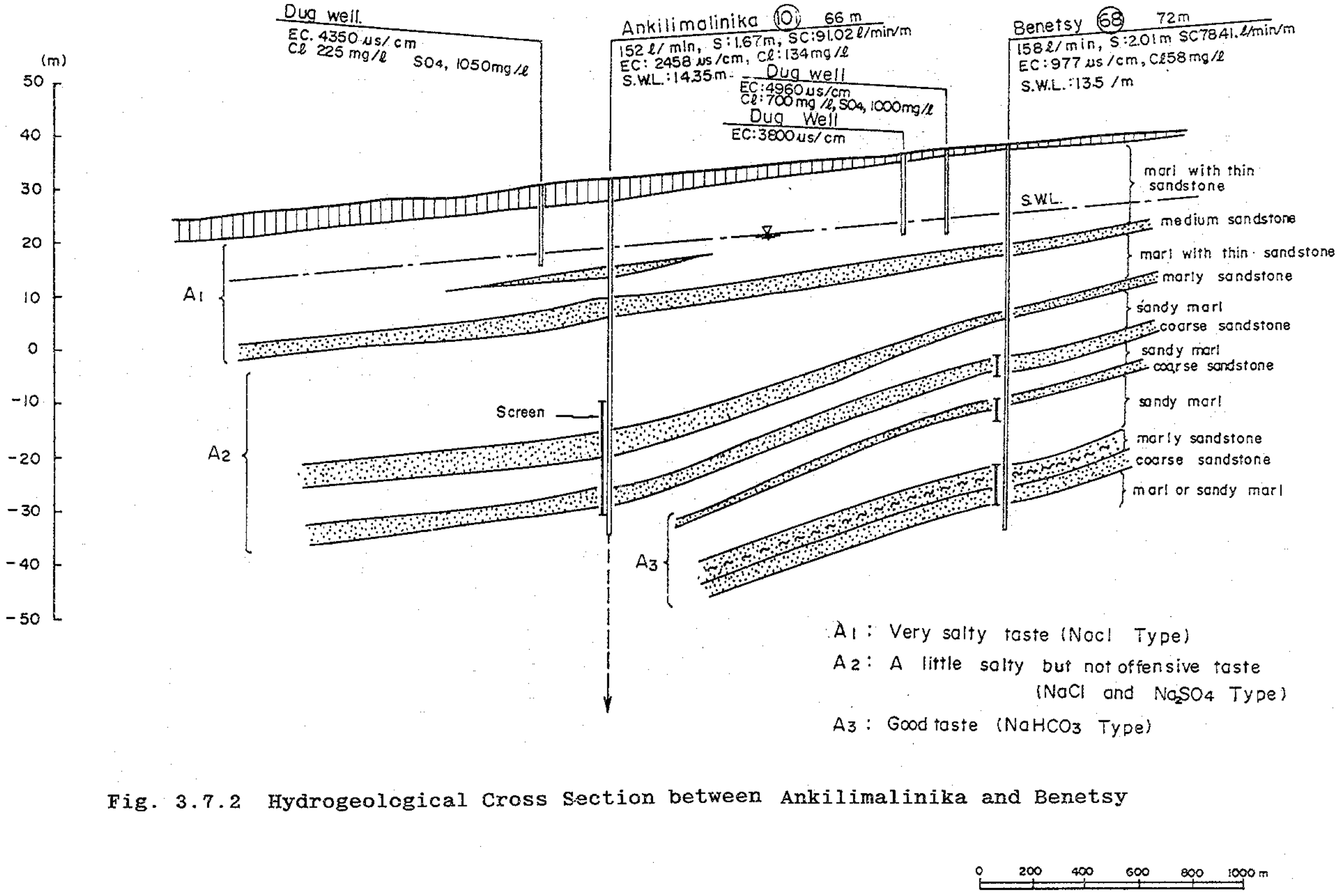


Fig. 3.7.2 Hydrogeological Cross Section between Ankilimalinika and Benetsy

3.8 Water Quality Analysis

Water quality analysis was performed on the samples collected from accessible candidate villages in the Study Area. The analytical items were selected in order to examine their suitability as drinking water, and to clarify the spatial characteristics of the quality of water in the Study Area.

The national standards for drinking water are not yet established in Madagascar. However, the international standards recommended by WHO are used, in principle, with appropriate modifications depending on water source and region. Table 3.8.1 shows the international standards by WHO, national standards in Japan and regional standards for drinking water which are used by JIRAMA in Toliara.

DR/200 type water quality test kits with built-in pH meter, conductivity/TDS meter, titrator, automatic photometer and several kinds of reagents were used in the analysis. The analytical items and analytical methods are listed in Table 3.8.2. Br, Cl2, I, Cr6+, Cu, and SO2 were not analyzed in Phase I of the study because many samples were turbid.

Water quality analysis was conducted on samples taken during Phase I from existing water sources, and during Phase II from the test boreholes, drilled as part of the study, as well as from additional springs and rivers.

3.8.1 Existing Water Sources

Results obtained from the analysis of samples from existing water sources such as dug wells, rivers and springs were graphed as trilinear diagrams (Fig. 3.8.1) showing the ion component of the water. Consequently, this subsection will be concerned with the joint discussion of ion components and potability of water in different areas.

(1) The water from villages numbered 1, 2, 3, 4, 8 and 9 is principally of the Sodium-Chlorine (NaCl : IV) type in Mangoky delta which is affected by sea water. The dissolved contents ranges from 20.7 mg/l in Ankida(9) to 1,240 mg/l at Ankilifolo(4).
The suitability for drinking water is generally good, as

shown in Appendix B-2. However, the ion contents of some water samples exceeded standards of drinking water, as shown below.

Befasy(3)	:	Fe-1.08 mg/l
Ankilifolo(4)	:	Cl-606 mg/l
Mangolovolo(8)	:	Fe-2.10 mg/l

(2) The water samples from villages numbered 5 to 7, 11 to 18, 21, 23 to 25, 28, 29, 54 to 59 and 63 to 67 are principally of the calcium-bicarbonate (Ca $(HCO_3)_2$: I) type which is similar to that of the river water or river-bed water in the Study Area. The dissolved contents range from 76 mg/l in Ankatrakatra(58) to 780 mg/l in Ampasikibo(55).

As shown below, the chemical quality of shallow groundwater in these villages is not totally satisfactory. In particular, the water from villages 53 to 59 and 63 to 67 has generally high ion contents (total hardness and Ca) exceeding the maximum limit of drinking water standards, and some samples have salty taste.

Andranomanitsy(11)	:	Ca-95 mg/l
Marobato(17)	:	Ca-85 mg/l
Antranosatra(21)	:	Fe-1.70 mg/l
Beranala(12)	:	Mn-1.3 mg/l
Ankilifolo(24)	:	Ca-168 mg/l
Analatelo(28)	:	Ca-154 mg/l
Belitsaka(54)	:	Ca-159 mg/l
Ampasikibo(55)	:	T/Hardness-652 mg/l , Ca-243 mg/l
Namaboha(56)	:	Ca-142 mg/l , Mn-2.4 mg/l
Ankatrakatra(58)	:	Fe-2.2 mg/l
Ampihamy(59)	:	Ca-98 mg/l
Manombo-Atm(63)	:	Ca-125 mg/l
Antandroka(64)	:	Ca-118 mg/l

(3) The water samples from Manoy(22) and Soahazo(52) are of the Sodium-Chlorine (NaCl :IV) type and Sodium-Sulphate (Na_2SO_4 :IV) type. The dissolved contents are 985 mg/l in Manoy(22) and 2,530 mg/l in Soahazo(52). The water quality in these villages is not acceptable due to high ion contents exceeding the maximum acceptable limit of the drinking water standards, and due to their salty taste.

Manoy(22) : Ca-142 mg/l
Soahazo(52) : T/hardness-1,120 mg/l , Ca-163 mg/l , Mg-172 mg/l , Cl-920 mg/l , SO_4-775 mg/l , TDS-2,530 mg/l

(4) The chemical quality of water from Basibasy(27) is of the Calcium-Chlorine ($CaCl_2$: III) type, rich in ion contents of Ca (210 mg/l), Mg (52 mg/l), Na (164 mg/l), K (45 mg/l), Cl (492 mg/l), and TDS-Total dissolved solids (1,160 mg/l). It is not of suitable quality as drinking water due mainly to its salty and bitter tastes.

(5) The water quality of Lake Ihotry was determined by the field survey in Phase II to have high electric conductivity ranging from 11,000 to 15,000 µS/cm and very salty taste. The results of water quality analysis are as follows.

Ion component	Sodium-Chlorine (NaCl :IV) type	
Ca	134	mg/l
Mg	164	mg/l
Na	2000	mg/l
K	56	mg/l
Cl	3270	mg/l
SO_4	600	mg/l
TDS	5450	mg/l

(6) Based on the preceding considerations (3) to (5) and the results of test drillings, the distribution of chemical quality and the flow mechanism of groundwater in these areas are estimated to be as shown in Fig. 3.8.2 and Fig 3.8.6.

(7) The chemical quality of shallow groundwater in Benetsy (68), Ankilimalinika(101), and Andrevo(69), rich in ion content of total hardness Ca, Mg, Na, K, Cl, SO_4 and TDS ,

is of the Sodium-Chlorine (NaCl :IV) and Sodium sulphate (Na_2SO_4 :IV) types. The dissolved contents range from 2,440 mg/l in Benetsy(68) to 4,680 mg/l in Andrevo(69). Therefore, the chemical quality of shallow groundwater in these villages is unsuitable for drinking water due mainly to its highly salty taste.

(8) The ion composition of the water in the coastal area including Tsivonoabe(76), directly affected by sea water, is of the Sodium-Chlorine (NaCl :IV) type. The hydrogeological section of this area is shown in Fig. 3.6.12. The groundwater development by borehole is very difficult in this area, except for shallow dug well.

(9) The chemical quality of shallow groundwater at Ambohimahavelona(80), Manoroka(81) and its surrounding area including JIRAMA pump station in Miary is of the Calcium-Bicarbonate ($Ca(HCO_3)_2$: I) type , and the suitability for drinking water is good.

(10) The chemical quality of shallow groundwater at Tranokaky(95), Andranovory(77) and their surrounding areas is of the Calcium-Bicarbonate ($Ca(HCO_3)_2$: I) type . The total dissolved contents are 317 mg/l in Tranokaky(95) and 242 mg/l in Andranovory(7).

(11) As shown in Fig. 3.8.2, the chemical quality of shallow groundwater in the area encompassing villages 36 to 40, 89, 92 and 99 is estimated to be of the Calcium-Sulphate ($CaSO_4$: III) or Calcium-Chlorine ($CaCl_2$: III) type. The dissolved contents range from 213 mg/l at Tanandava(40) to 389 mg/l at Ankilimitraloka(99).
As for the suitability for drinking water, the following results are pointed out from the water quality analysis.

Betsinefo(39) : Ca-98mg/l
Mahaboboka(92) : salty and bitter taste
Ankilimitraloka(99): Ca-92 mg/l , Mn-0.6 mg/l

(12) The water quality in candidate villages numbered 33 to 35, 97 and 100 is of the Sodium-Bicarbonate (NaHCO3 : II) type. The dissolved contents range from a low 12.7 mg/l at Andranomanitsy(33) to a high 68.0 mg/l at Ampandramitsitaky(35). The water quality in these villages is generally

good for drinking. However, the water samples taken from Antanimora(97) and Ankilivalo(100) contained Fe ion in excess of the maximum limit of 1.0 mg/l.

(13) The water quality in the area which is composed of villages numbered 41, 42, 47, 49, 50, 82, 83, 90 and 91 is estimated to be of the Calcium-Bicarbonate (Ca $(HCO_3)_2$: I) type. The dissolved contents range from a low 25.7 mg/l at Laborana(82) to a high 430 mg/l at Tanambao (90).The water quality in the area is generally good for drinking.

(14) As shown in Fig. 3.8.2, in the eastern part of the Study Area which is mainly composed of Isalo II formation, the chemical quality of water is principally of the Sodium-Chlorine (NaCl :IV) or Sodium-Sulphate (Na_2SO4) types. The dissolved contents has a very low value of less than 30 mg/l, except for Berenty-Betsileo(46) and its surrounding area where salty taste water is commonly found.

3.8.2 Test Wells

(1) Potability

The chemical quality of groundwater samples taken from newly drilled boreholes is generally good as drinking water, as shown in Table 3.8.3. However, some water samples taken from the neritic sediments of the Middle to Upper Eocene in the western region of the Study Area had high ion contents exceeding the maximum limit of the standards for drinking water. These items are as follows.

Village	Item	Result(mg/l)	Max. Limit
Manoy(22)	Hardness	530	500
	F	1.29	0.8
Basibasy(27)	Hardness	1060	500
	Ca	292	200
	Cl	720	600
Belitsaka(54)	Hardness	748	500
Ankilimali-nika(101)	SO_4	525	400
	F	1.11	0.8

Groundwater quality in Basibasy(27) is not suitable as drinking water, having salty and bitter tastes. In Berenty-Betsileo, the water from the newly drilled borehole was salty. However, the chemical quality of this groundwater meets the standards for drinking water, as shown in Table 3.8.3.

(2) Ion component and water types

From the results of water quality analyses, trilinear diagrams (Fig. 3.8.3) and hexadiagrams (Fig.3.8.4) were drawn. Based on these data, the properties of ion component of groundwater in the Study Area are summarized as follows.

(a) The water from springs, streams and river flows which are mainly discharged from groundwater is principally of the calcium-bicarbonate($Ca(HCO_3)_2$:I) type. The dissolved contents range from a low 54 mg/l in the Fiherenana River at Antaralava to a high 222 mg/l in the springs at Ambobo-ka.

(b) The ion composition of the groundwater from the neritic sediments of the Middle to Upper Eocene in the western region of the Study Area is generally of the calcium-bicarbonate($Ca(HCO_3)_2$:I) type, except for the groundwater of Manoy(22), Basibasy(27), Soahazo(52)-2(shallow borehole), Belitsaka(54), Benetsy(68), Manoroka(81) and Ankilimalinika(101).

This ion component of the groundwater from the neritic sediments is similar to that of the springs and streams. The groundwater flow mechanism in the region is estimated as shown in Fig. 3.8.6 and Fig. 3.8.7.

(c) The ion component of the groundwater at Manoy(22), Basibasy(27) and Belitsaka(54) is of the calcium-sulphate($CaSO_4$:III) or calcium-chlorine($CaCl_2$:III) types. The dissolved contents range from a low 760 mg/l at Manoy(22) to a high 1,370 mg/l at Basibasy(28).

The groundwater flow mechanism in this area is estimated as shown in Fig. 3.8.6.

(d) The groundwater at Benetsy(68) is of the sodium-bicarbonate($NaHCO_3$:II) type, and the groundwater at Ankilimalinika is of the sodium-chlorine(NaCl:IV) and sodium-sulphate(Na_2SO_4:IV) type.

The dissolved contents are 489 mg/l at Benetsy(68) and 1,230 mg/l at Ankilimalinika(101). The water from shallow wells in this area is very salty and, therefore, not suitable as drinking water (See Table 3.8.3).

In this Study, 2 boreholes with a depth of 62m to 72m were drilled in Ankilimalinika(101) and Benetsy(68) with the purpose of clarifying the realities of the so-called salty tasting water. The results of this test drilling were decribed in Subsection 3.7.1. The realities of the so-called salty taste water are as shown in Fig. 3.8.2 and Fig. 3.7.2. This hydrogeological condition shown in Fig. 3.8.2 and Fig.3.7.2 is mostly similar to that of the Soahazo area(52).

(e) The ion component of the groundwater in limestone of the Lower Eocene (at Befoly(78)) and in basaltic rocks of the Upper Cretaceous (at Tranokaky(95)) is of the calcium-bicarbonate($Ca(HCO_3)_2$:I) type. The dissolved contents are 202 mg/l at Befoly(78) and 447 mg/l at Tranokaky(95).

As for the groundwater flow mechanism in this area, it is estimated as shown in Fig. 3.8.5.

(f) The ion component of the groundwater in the Middle Jurassic continental deposit (Isalo III) is of the calcium-bicarbonate ($Ca(HCO_3)_2$:I) type, and the dissolved content is 205 mg/l at Tandrano(34).

(g) The aquifers of the Lower Jurassic continental deposits (Isalo II) are mostly of the sodium-bicarbonate ($NaHCO_3$:II) type. The dissolved contents are 53mg/l at Berenty-Betsileo(46).

The groundwater flow mechanism in this area is estimated as shown in Fig.3.8.5.

3.8.3 Tritium Concentration

In this study, in order to estimate the groundwater age and to consider the groundwater flow mechanism, 5 groundwater samples from the newly drilled boreholes at Manoy(22), Soahazo(52), Befoly(78), Tranokaky(95), and Maninday(88) were taken to Japan to analyze the radioisotope(H3). The results of this analysis are shown in Table 3.8.4.

(1) General

Determining the tritium concentration(TR) is a useful technique to estimate the age of the underground water.

Tritium is a radioactive isotope of hydrogen, having a half life of 12.3 years. The occurrence of tritium in water of the hydrological cycle arises from both natural and man-made sources. Tritium is produced naturally in the earth's atmosphere by the interaction of cosmic-ray-produced neutrons with nitrogen. Until 1952, the average natural tritium content of precipitation world-wide was in the range of about 5-20TR. With the beginning of large scale atmospheric testing of thermonuclear bombs in 1952, the tritium contents of precipitations rose sharply
In 1962-1963, they reached a maximum of about 80000TR in some localities, over a thousand times greater than that prior to nuclear bomb testing. With the restrictions of atmospheric testing, tritium contents have been declining, but they still remain in larger concentrations than naturally produced. Tritium is widely used for groundwater dating in the following contexts:

1) Very low tritium concentrations, around the level of detectability, show that the water principally is from the pre-bomb period. Relatively high tritium concentrations indicate the water originates partly or wholly from post-bomb precipitation.

2) For more precise tritium dating, the changing rainfall regime has to be taken into account.
Assuming that piston flow occurs, the dating of water can be achieved by applying the following equation of decay.

$$\ln(A) = \ln(B) - t/th_{*} \ln(2)$$

where,
A : Tritium concentration of the sample
B : Tritium concentration in precipitation (t years earlier)
t : Age of the water
th: Half-life of tritium (12.262 years)

3) Fig.3.8.8 shows the variation of tritium concentration in rain at Pretoria, South Africa from 1976 to 1984.
From this variation of tritium concentration, an average value of 12.626TR can be obtained.

(2) Considerations

1) Assuming that the original tritium concentration in the Study Area keeps a constant value of 12.6TR, and groundwater movement in an aquifer follows the piston flow, a decay curve of tritium concentration to estimate the groundwater age can be drawn as shown in Fig.3.8.9.

2) Analysis results indicate that tritium concentration in the groundwater of the Study Area is generally low, ranging from 0.96TR at Manoy(22) to 3.66TR at Maninday(88). However, as shown in Fig.3.8.9, three groups can be ascertained.

Group A:0.96TR at Manoy(22), 1.05TR at Soahazo(52)
(Estimated age of water is about 45 years)
Group B:1.65TR at Tranokaky(95)
(Estimated age of water is about 36 years)
Group C:3.54TR at Befoly(78), 3.66TR at Maninday(88)
(Estimated age of water is about 23 years)

3) The borehole at Manoy (22) is located near the downstream area where the perennial stream of Befandriana River becomes an underground river. The aquifer located between 14.8m and 38.4m below the ground level has lithofacies

composed of medium to coarse sandstone of the Middle to Upper Eocene. Thus, the main recharge source of shallow groundwater at Manoy(22) is estimated to be the perennial Befandriana River.

However, tritium concentration at Manoy(22) was only 0.96TR, which is a low value suggesting that little recharge from surface water exists, and therefore groundwater in this region is very old.
Judging from the low value of tritium concentration and the hydrogeological condition(see Fig.3.8.6), groundwater in this region seems to be supplied mainly from lateral recharge and vertical recharge from underlying aquifer with some fossil water.

The hydrological environment in Soahazo region is different from that of Manoy region as shown in the hydrogeological map. However, the hydrogeological conditions in Soahazo region, such as recharge and flow mechanisms of groundwater, are considered to be very similar to those of Manoy region.

These considerations for recharge and flow mechanisms of groundwater, based on the result of tritium analysis, agree with those of the earlier considerations on the properties of ion components of groundwater.

4) The main aquifer of the borehole at Tranokaky(95) consists of fissured basaltic rocks of the Upper Cretaceous, and the hydrogeological conditions of the region is estimated as shown in Fig.3.8.5.
Judging from these hydrogeological conditions, calcium-bicarbonate [$Ca(HCO_3)_2$:I] type groundwater, and a low value of tritium concentration(1.65TR), groundwater in this region seems to be supplied mainly from lateral recharge, having flowed very slowly from the foot of the mountains.

5) The borehole at Befoly(78) is located in the region of limestone of the Lower Eocene, and the borehole at Maninday(88) is located in the region that is composed of continental deposits of the Lower Jurassic(Isalo II). These lithofacies are the most representative aquifers covering a wide area in the Study Area.
Therefore, tritium concentrations of 3.54TR-3.66TR obtained

in Befoly and Maninday seem to be common in groundwater of the Study Area.

As shown in Fig.3.8.5, groundwater in these regions seems to be supplied mainly from lateral recharge, flowing at a circulation rate of 20 to 25 years.

Table 3.8.1 Drinking Water Quality Standard

(1) Physical Condition

Item	WHO Highest desirable	WHO Maximum permissible	Japan
Color	15	50	5
Taste	not offensive	not offensive	not offensive
Odor	"	" * (")	"
Turbidity	5	25 (50)	2
pH	6.5 to 8.5	6.5 to 9.2 (7.5 to 8.5)	5.8 to 8.6

(2) Toxin

Item	WHO	Japan
Hg	0.001	None
Pb	0.1	0.1
As	0.05	0.05
Se	0.01	0.01
Cr 6+	0.05	0.05
CN	0.1	None
Cd	0.005	0.01

(3) Bacteriological condition

Item	WHO	Japan
Standard Plate Count (Colonies/cm^2)	–	100
MPN (Coliform organism/ 100 m3)	–	None
E.Coli	–	–

(4) Chemical condition

Item	WHO Highest desirable	WHO Maximum permissible	Japan
Total solids (mg/l)	500	1,500 (1500)	–
Fe	0.1	1.0 (1.0)	0.3
Mn	0.05	0.5 (0.5)	0.3
Fe + Mn	–	–	–
Cu	0.005	1.5	1.0
Ca	75	200 (75)	–
Mg	30	150 (150)	–
SO4	200	400 (400)	–
Cl	200	600 (600)	200
F	0.6	–	0.8
NO3	10	– (45)	10
Alkylbenzal Sulfohates, ABS	0.5	–	0.5
Phenolic-substance asphenol	0.001	–	0.005
Hardness	100	500	300

* ( ) : Drinking water quality standards which are used by JIRAMA in Toliara

Table 3.8.2 Items and Methods used in Water Quality Analysis

Item	Instrument	Method of Analysis
pH	pH Meter	Ion Electrode Method
T-Hardness	Digital Titrator	Titration with EDTA Standard Solution (pH 10)
Ca	Digital Titrator	Titration with EDTA Standard Solution (pH 12)
Mg	Digital Titrator	Titration with EDTA Standard Solution
Cl	Digital Titrator	Titration with $Hg(NO_3)_2$ Standard Solution
SO_4	Automatic Photometer	Barium Sulfate Turbidity Method
Fe	Automatic Photometer	O-phenanthroline Method (Total)
TDS	Conductivity Meter	Electrolytic Conductivity Method (EC x 0.5)
EC	Conductivity Meter	Electrolytic Conductivity Method
Acidity	Digital Titrator	Titration with NaOH Standard Solution
Alkalinity	Digital Titrator	Titration with H_2SO_4 Standard Solution
PO_4	Automatic Photometer	Molybdenum Blue Method with Ascorbic Acid
NH_3-N	Automatic Photometer	Nessler Reagent Method
NO_2-N	Automatic Photometer	Diazotization Method
NO_3-N	Automatic Photometer	Diazotization Method with Cadmium Metal Reduction
F	Automatic Photometer	SPADNS Solution Method
Mn	Automatic Photometer	Periodate Oxidation Method
E. coli	Automatic Photometer	Coli Forms Detection Paper
TURBIDITY & COLOR		View after Precipitation

Table 3.8.3 Water Analysis Results of Test Drilling Wells

No.	LOCATION	DATE	Temp.	pH	Hard.	Ca	Mg	Na	K	Cl	SO4	Fe	TDS	EC	Acid.	Alkali	PO4	NH3-N	NO2-N	NO3-N	F	Mn	E.coli	NOTE
1	22 MANOY	90/09/31	28.5	7.1	530	184.0	17.0	115.0	14.0	288	140	0.00	760.0	1520	112	236	0.03	0.00	0.007	0.9	1.29	0.0		42.0m
2	23 AMPOZA	90/08/24	30.2	7.3	150	52.0	4.8	18.0	9.6	12	0	0.00	184.0	368	52	200	0.03	0.02	0.001	0.1	0.56	0.0		58.0m
3	25 SIHANAKA	90/09/06	29.6	7.5	122	46.0	1.9	15.0	8.6	11	0	0.00	155.0	310	54	160	0.03	0.00	0.000	0.0	0.77	0.3		41.0m
4	27 BASIBASY	90/10/06	28.5	6.8	1060	292.0	80.0	130.0	16.0	720	31	0.04	1370.0	2740	100	284	0.03	0.00	0.071	0.1	0.44	0.0		83.0m
5	28 ANALATELO	90/10/01	29.0	7.4	145	54.0	2.7	19.0	4.5	12	11	0.00	181.0	362	40	170	0.02	0.24	0.300	0.6	0.20	0.0		35.0m
6	29 MANGOTROKA	90/09/12	20.5	7.0	40	13.0	3.4	15.0	2.8	12	9	0.01	71.5	141	10	54	0.02	0.04	0.009	0.3	0.19	0.0		41.0m
7	52-1 SOAHAZO	90/07/13	28.0	7.3	342	91.0	28.0	88.0	5.1	70	158	0.00	540.0	1080	92	276	0.07	0.00	0.090	0.0	0.86	0.0		76.0m
8	52-2 SOAHAZO	90/07/17	27.3	7.4	696	122.0	95.0	576.0	10.0	252	1200	0.00	1820.0	3630	76	500	0.04	0.16	0.000	0.0	1.18	0.0		34.0m
9	53 ANALAMISAMPY	90/07/27	23.5	7.2	464	128.0	35.0	101.0	9.2	206	34	0.00	675.0	1350	104	300	0.04	2.07	0.000	0.8	0.61	0.1	+	71.3m
10	54 BELITSAKA	90/09/01	28.5	7.0	748	173.0	76.0	129.0	10.0	444	73	0.00	1040.0	2080	132	336	0.01	0.11	0.000	0.0	0.24	0.0	-	66.0m
11	55 AMPASIKIBO	90/08/06	27.5	7.2	308	114.0	5.8	52.0	5.4	22	100	0.02	409.0	817	70	312	0.03	0.15	0.002	0.7	0.25	0.0	-	50.0m
12	56 NAMABOHA	90/08/16	27.5	7.3	298	104.0	9.2	88.0	4.9	95	70	0.01	488.0	975	119	294	0.09	0.01	0.011	0.3	0.21	0.0	-	83.0m
13	59 AMPIHAMY	90/10/13	27.8	7.2	296	110.0	4.8	26.0	8.2	86	73	0.00	498.0	996	72	288	0.05	0.00	0.000	0.0	0.61	0.0		53.0m
14	65 ANKARAOBATO	90/07/01	27.8	7.2	320	101.0	16.0	56.0	7.4	62	65	0.00	425.0	849	52	320	0.04	0.00	0.001	0.0	0.47	0.0		75.5m
15	63 MANOMBO ATM	90/10/13	28.5	7.2	406	118.0	27.0	40.0	12.0	62	160	0.02	500.0	1000	64	264	0.05	0.06	0.001	1.9	0.53	0.0	-	27.0m
16	68 BENETSY	90/10/22	27.5	7.4	140	45.0	6.5	167.0	2.2	58	105	0.00	489.0	977	80	332	0.02	0.00	0.001	0.0	0.50	0.2	-	45.0m
17	67 TSEFANOKA	90/10/25	28.5	7.4	182	57.0	9.7	59.0	0.3	10	68	0.00	301.0	602	42	234	0.06	0.00	0.001	0.0	0.93	0.0	+	72.0m
18	101 ANKILIMALINIKA	90/10/31	28.4	7.5	134	39.0	8.7	501.0	2.7	134	525	0.00	1230.0	2450	70	492	0.01	0.00	0.000	0.6	1.11	0.0	-	66.0m
19	81 MANOROKA	90/10/28	29.0	7.4	246	56.0	26.0	126.0	11.0	95	90	0.01	605.0	1210	42	236	0.01	0.31	0.003	0.2	0.51	0.2		58.0m
20	78 BEFOLY	90/09/14		7.6	194	53.0	12.0	1.4	6.4	14	63	0.00	202.0	403	10	124	0.05	0.01	0.001	0.0	0.31	0.0		226.5m
21	95 TRANOKAKY	90/07/23		7.5	358	90.0	32.0	43.0	7.9	62	70	0.00	447.0	894	62	314	0.10	0.00	0.001	0.1	0.26	0.0		181.1m
22	34 TANDRANO	90/08/26		7.4	162	54.0	6.8	10.0	12.0	16	46	0.03	205.0	410	48	126	0.17	0.03	0.002	0.0	0.93	0.0		158.1m
23	46 BERENTY-BETSILEO	90/09/06		8.4	20	6.4	1.0	468.0	10.0	248	113	0.10	1100.0	2190	50	626	0.07	0.00	0.200	3.6	0.81	0.0		140.6m
24	88 MANINDAY	90/07/31		6.9	20	5.6	1.5	12.0	1.2	10	0	0.01	53.0	106	14	28	0.10	0.12	0.009	0.0	0.02	0.0		73.5m
25	96 ANALAMARY	90/08/15		6.1	30	3.8	1.9	12.0	8.6	10	12	0.15	71.0	142	14	36	0.28	0.00	0.003	0.2	0.39	0.1		204.0m
26	BEFANDRIANA	90/09/25	28.3	7.1	260	53.0	31.0	14.0	2.1	16	36	0.00	283.0	565	78	244	0.03	0.00	0.001	0.0	0.53	0.0		53.3m
27	BERENTY RIVER	90/09/06		7.8	78	22.0	5.8	8.9	5.2	6	3	0.15	98.0	196	24	100	0.08	0.00	0.004	0.0	0.21	0.0		
28	FIHERENANA RIVER	90/09/11		7.1	38	8.6	3.9	5.0	5.7	12	10	0.20	54.0	107	18	34	0.02	0.05	0.002	0.0	0.18	0.0		
29	MANOMBO RIVER	90/09/22		7.8	180	62.0	5.6	2.3	0.9	12	49	0.00	162.0	323	34	140	0.01	0.00	0.044	0.0	0.04	0.0		
30	UINETA RIVER	90/09/11		7.7	254	68.0	20.0	27.0	2.1	45	45	0.00	310.0	619	46	206	0.05	0.00	0.003	0.0	0.34	0.0		
31	59 AMPIHAMY D.W.	90/10/12	27.5	7.3	310	97.0	16.0	134.0	12.0	104	150	0.00	605.0	1210	78	320	0.00	0.00	0.001	0.2	0.50	0.0		
32	68 BENETSY D.W.	90/10/24	28.1	7.4	580	150.0	49.0	915.0	4.8	700	1000	0.22	2480.0	4960	140	632	0.16	5.40	0.060	13.0	0.80	0.0	+	
33	ANKILIMALINIKA D.W.	90/10/24	28.4	7.5	184	40.0	15.0	975.0	2.1	225	1050	0.07	2180.0	4350	129	934	0.10	0.05	0.257	7.9	1.11	0.4	+	
34	ANDRANOMENA SPRING	90/07/19		7.6	190	58.0	11.0	7.3	3.5	6	21	0.00	207.0	413	40	184	0.05	0.00	0.000	0.0	0.00	0.0		
35	AMBOBOKA SPRING	90/07/18		7.4	194	68.0	5.8	12.0	2.0	8	24	0.00	222.0	443	30	180	0.06	0.00	0.003	0.3	0.50	0.0		
36	IHOTRY LAKE SOUTH	90/07/18		5.9	1010	134.0	164.0	2000.0	56.0	3270	600	0.01	5450.0	10900	56	188	0.07	0.10	0.001	0.7	0.00	0.0		

Temp.: °C
Hard. Acid. Alkali.: mg/l as $CaCO_3$
EC: μS/cm
Other item: mg/l

Table 3.8.4 Tritium Concentration

Sampling Place (No. of Borehole)	Aquifer		Tr Value
	Aquifer Characteristics	Screen Position (GL-m)	
Manoy (no. 22)	·Medium to coarse sandstone of the Middle to Upper Eocene ·Unconfined aquifer	①18.4-38.4	0.96 (±0.07)
Soahazo (No. 52-1)	·Sandy marl with medium to coarse sdand-stone of the Middle to Upper Eocene ·Weakly confined aquifer	①47.1-63.1	1.05 (±0.07)
Befoly (No. 78)	·Weakly fissured and porous limestone of the Lower Eocene ·Unconfined aquifer	①183.5-198 ②224.5-226.5 (Open hole)	3.54 (±0.11)
Tranokaky (No. 95)	·Fractured basalt and fine sandstone of the Upper Cretaceous ·Weakly confined aquifer	①35.5-55.5 ④99.5-103.5 ②59.5-63.5 ⑤115.5-135.5 ③75.5-83.5	1.65 (±0.07)
Maninday (No. 88)	·Weathered coarse sandstone of the Lower Jurassic ·Mainly unconfined aquifer	①15.5-31.5 ②35.5-43.5 ③51.5-55.5	3.66 (±0.12)

1-100:
No. of Water Samples taken from Candidate Villages

101-115:
101: 16
102: 27
103: Antanimieva
104: Ankazoabo
105: 52
106: 65
107: 68
108: 68
109: 69
110: 69
111: 77
112: 81
113: 94
114: 95
115: Toliara

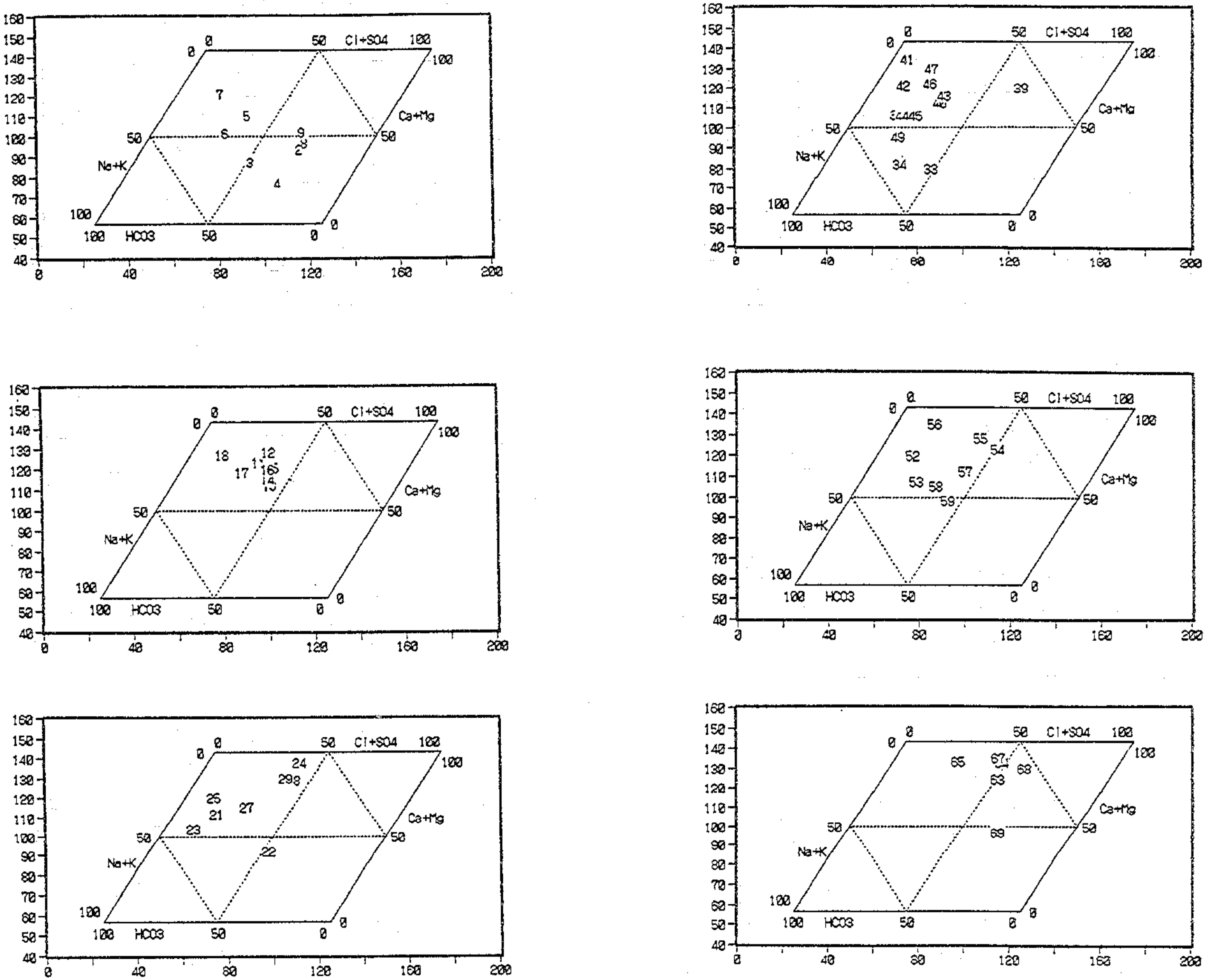


Fig. 3.8.1 Trilinear Diagrams of Shallow Groundwater (1)

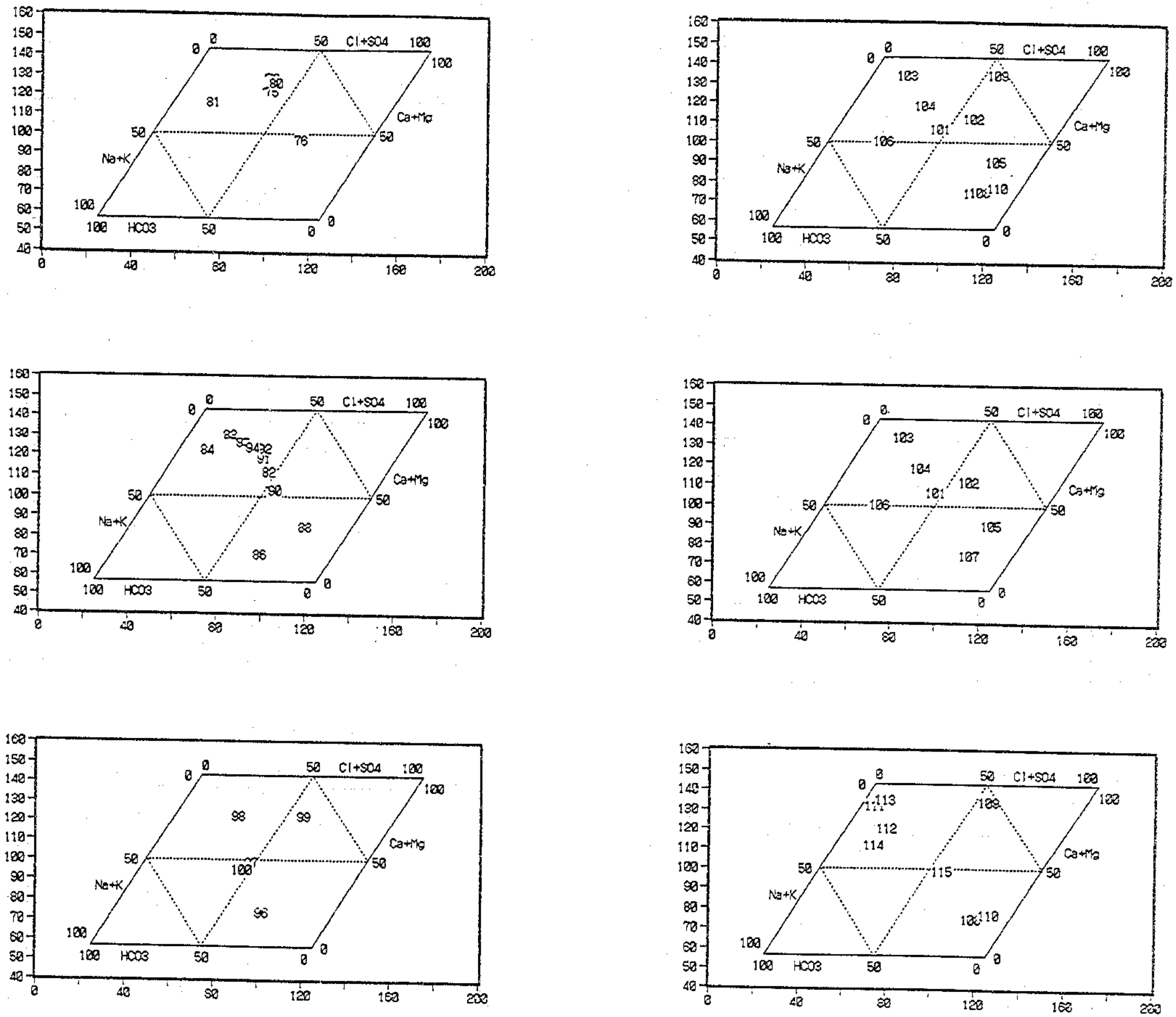


Fig. 3.8.1 Trilinear Diagrams of Shallow Groundwater (2)

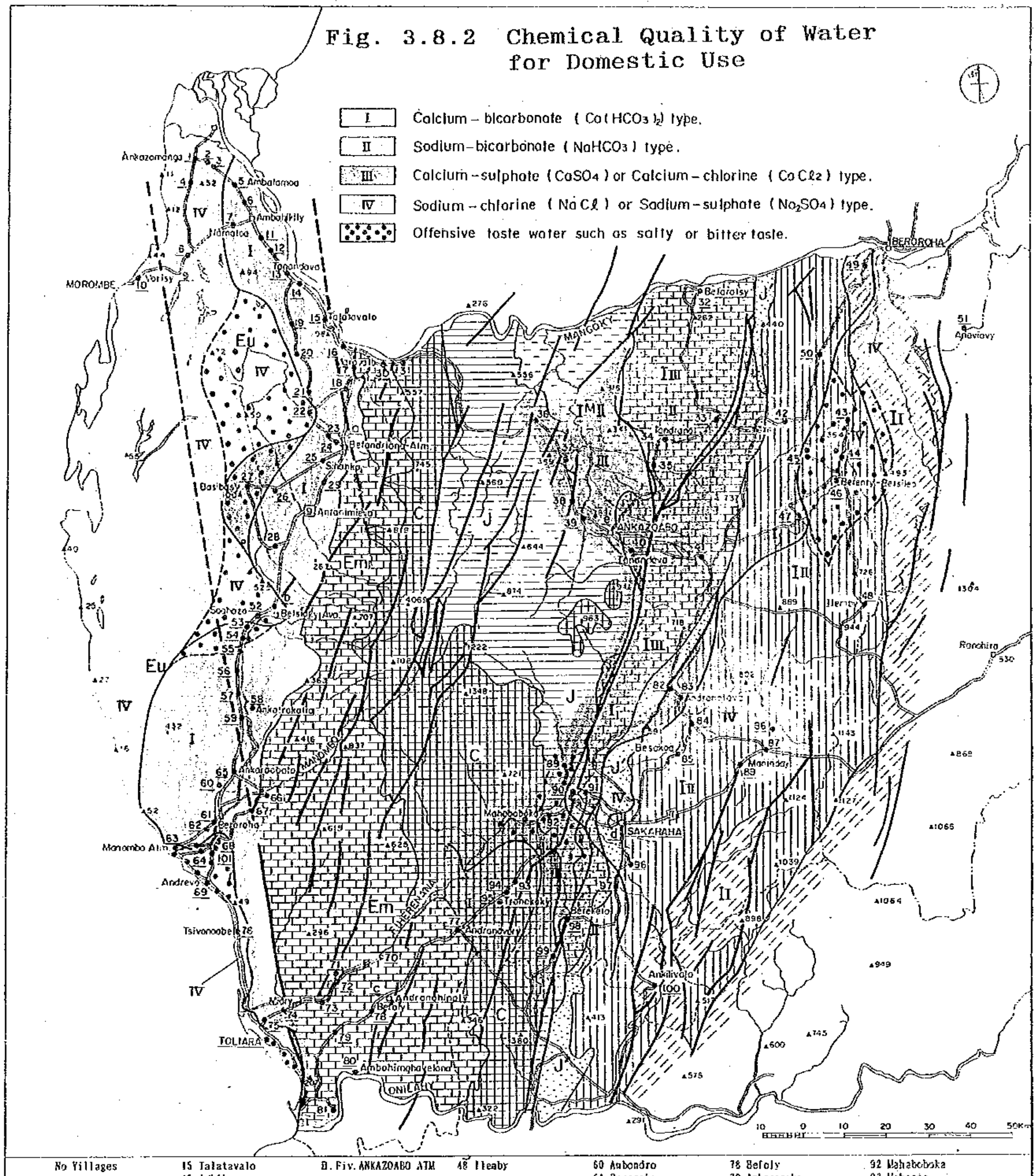


Fig. 3.8.2 Chemical Quality of Water for Domestic Use

No Villages

I. Fiv. MOROMBE

1 Ankazomanga
2 Beadabo
3 befasy
4 Ankilifolo(1)
5 Ambalamoa
6 Tsianihy
7 Namatoa
8 Mangolovolo
9 Ankida
10 Vorisy
11 Andranomanitsy
12 Berantala
13 Tanandava
14 Antsakoabe
15 Talatavalo
16 Ambiky
17 Marovato
18 Andranoboka
19 Satrambondro
20 Mahavozokely
21 Antranosatra
22 Manoy
23 Ampoza
24 Ankilifolo(2)
25 Sihanaka
26 Bemoka
27 Basibasy
28 Analatelo
29 Mangotroka
30 Nosy-Ambositra
31 Tsiarimpioke

II. Fiv. ANKAZOABO ATM

32 Betaratsy
33 Andranomanintsy
34 Tandrano
35 Ampandramitsetaky-
36 Andranomafana
37 Mamakiala
38 Berenty-Ankilimasy
39 Betsinefo
40 Tanandava
41 Ampoza
42 Ipetsa Atm
43 Mandabe Atm
44 Soatanimbary
45 Sahanory Atn
46 Berenty-Betsileo
47 Ankilivalokely
48 Ileaby

III. Fiv. BEROROHA

49 Tanandava-Antaifasy
50 Anjamitikitra
51 Anaviavy

IV. Fiv. TOLIARA I / II

52 Soahazo
53 Analamisampy
54 Belitsaka
55 Ampasikibo
56 Namaboha
57 Antseva
58 Ankilimiavotoka
59 Ampihamy
60 Ambondro
61 Beroroha
62 Antsonarify
63 Manombo-Atn
64 Antandroka
65 Ankaraobato
66 Andoharano
67 Tsefanoka
68 Benetsy
69 Andrevo
70 Anjamala
71 Ampihalia
72 Behompy
73 Ambolonkira
74 miary
75 Befanamy
76 Tsivonoabe
77 Andranovory
78 Befoly
79 Ankororoka
80 Ambohimahavelona
81 Manoroka
101 Ankilimalinika

V. Fiv. SAKARAHA

82 Iaborana
83 Andranolava
84 Lambomakandro
85 Besakoa(1)
86 Besakoa(2)
87 Ampandra
88 Maninday
89 Bevoalavo
90 Tanambao
91 Ambahimalitsy
92 Mahaboboka
93 Mahasoa
94 Andamasiny-Vineta
95 Tranokaky
96 Analamary
97 Antanimora
98 Bereketa
99 Ankilimitraloka
100 Ankilivalo

a Befandriana
b Betsioky Nord
c Andranohinaly
d Sakaraha
e Ankazoabo

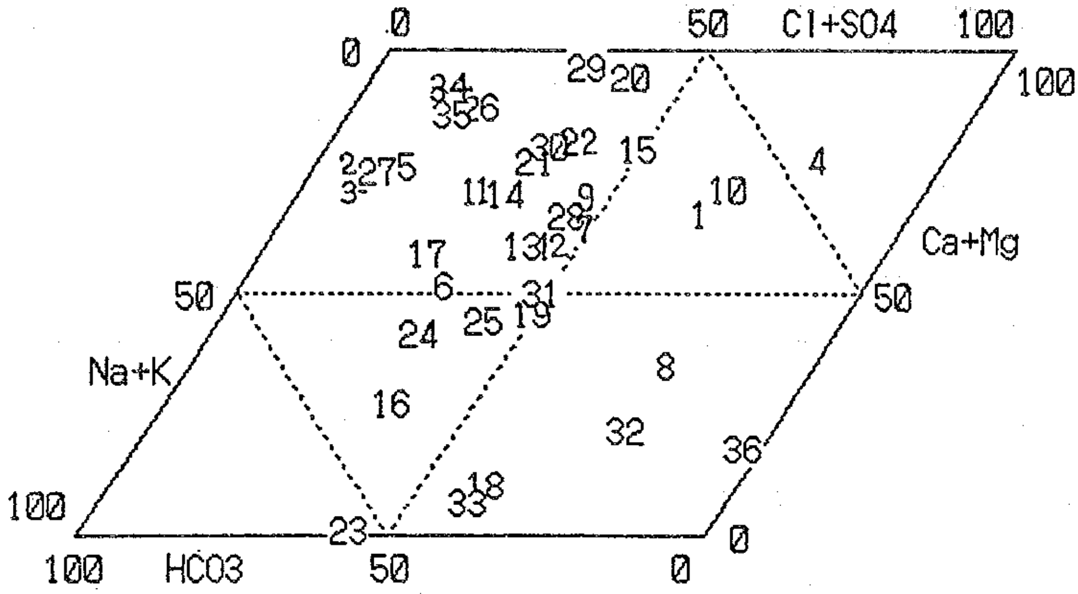
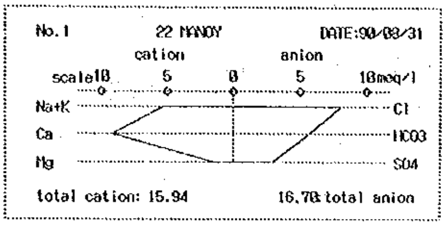
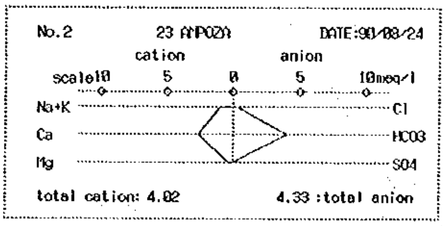
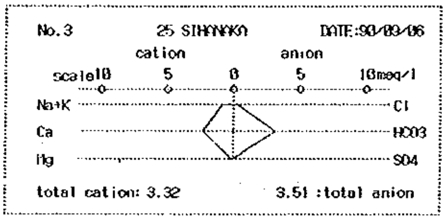
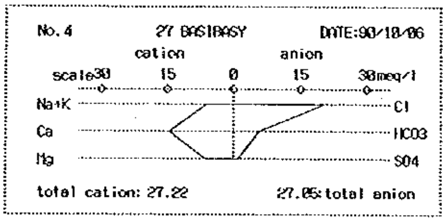


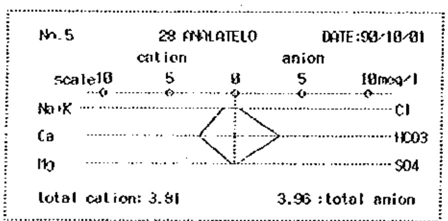
Fig. 3.8.3 Trilinear Diagram of Test Drilling Wells

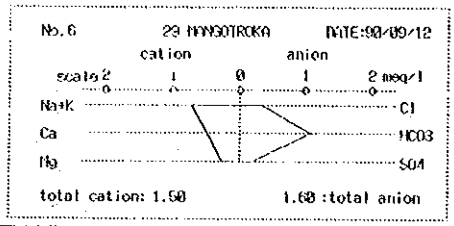


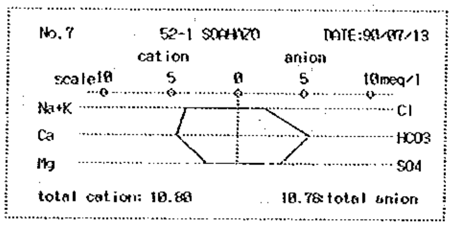


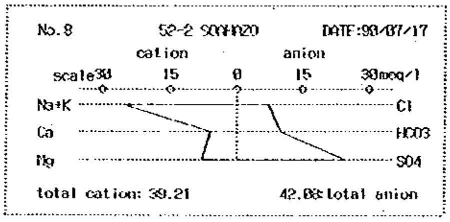


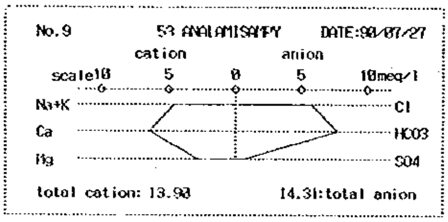












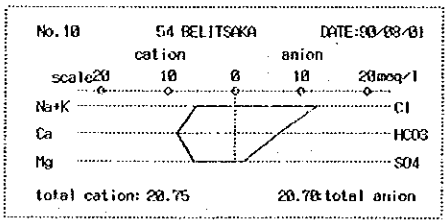
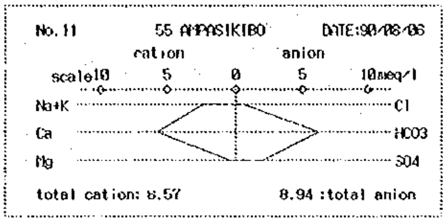
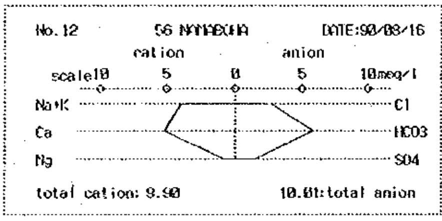
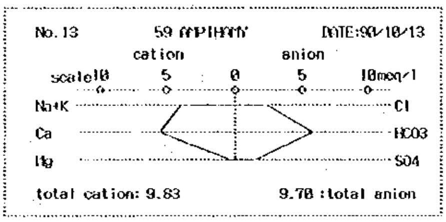
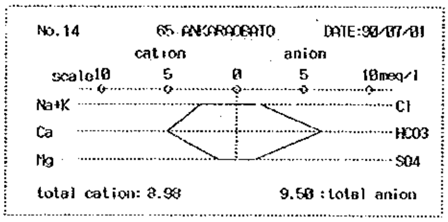


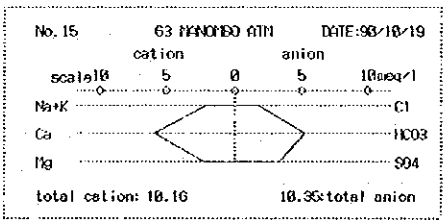
Fig. 3.8.4 Hexadiagram of Test Drilling Wells (1)

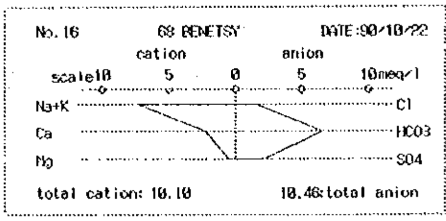


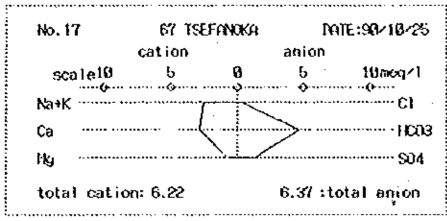


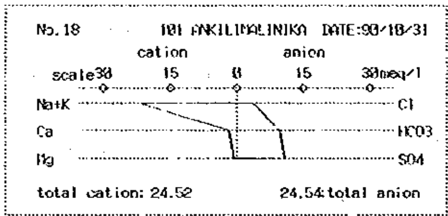


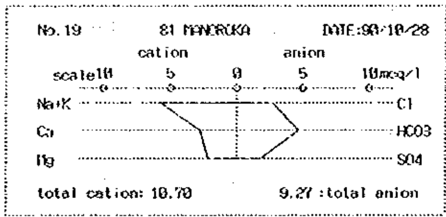












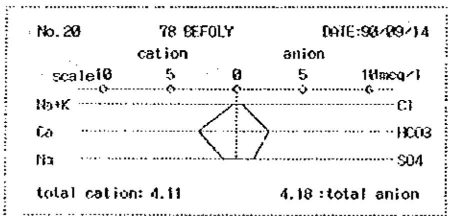
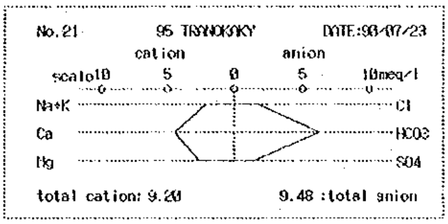
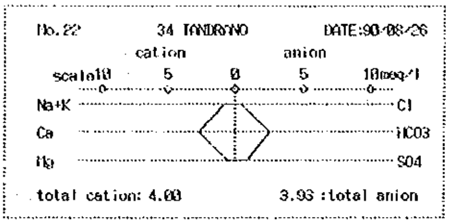
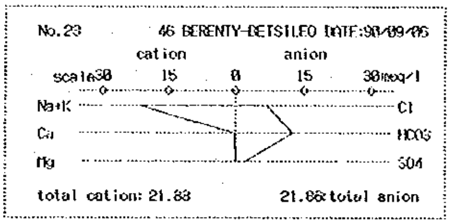
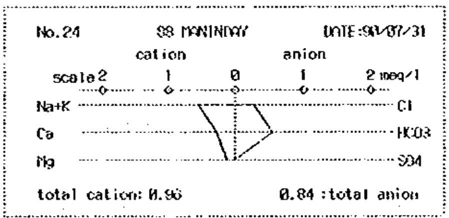


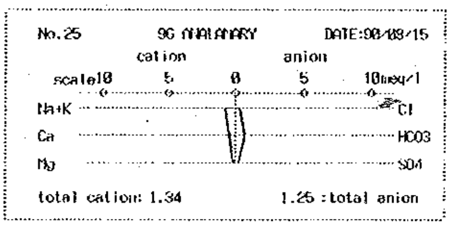
Fig. 3.8.4 Hexadiagram of Test Drilling Wells (2)

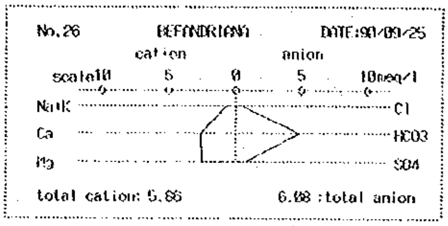


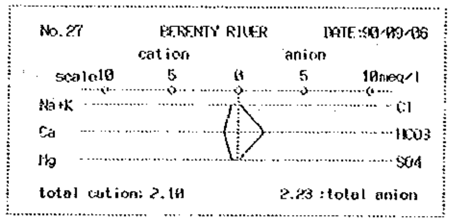


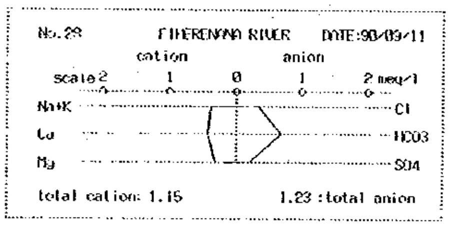


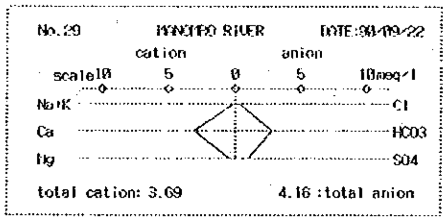












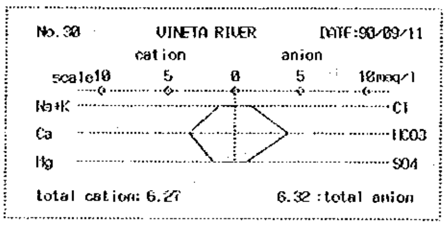
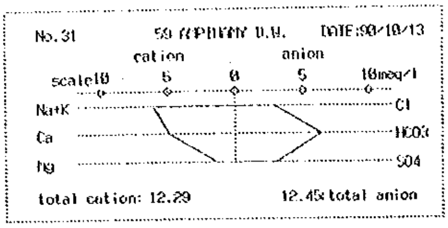
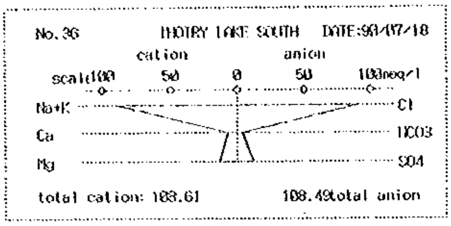
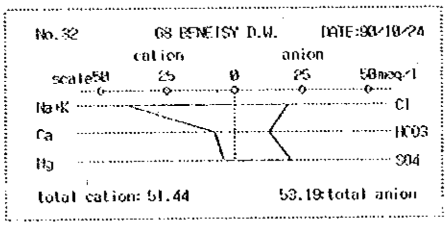
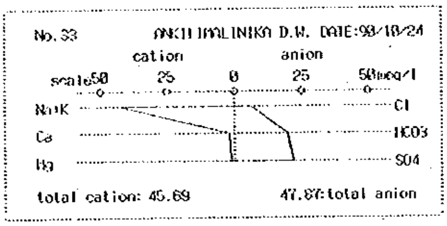


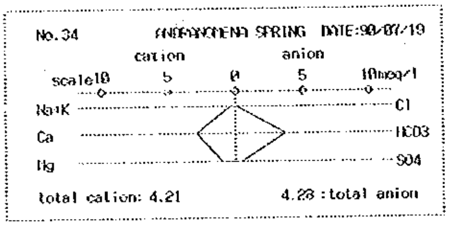
Fig. 3.8.4 Hexadiagram of Test Drilling Wells (3)











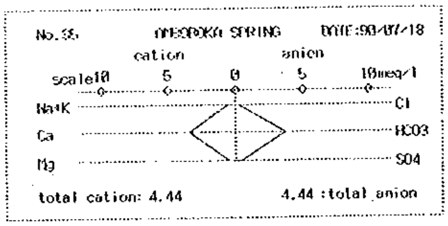
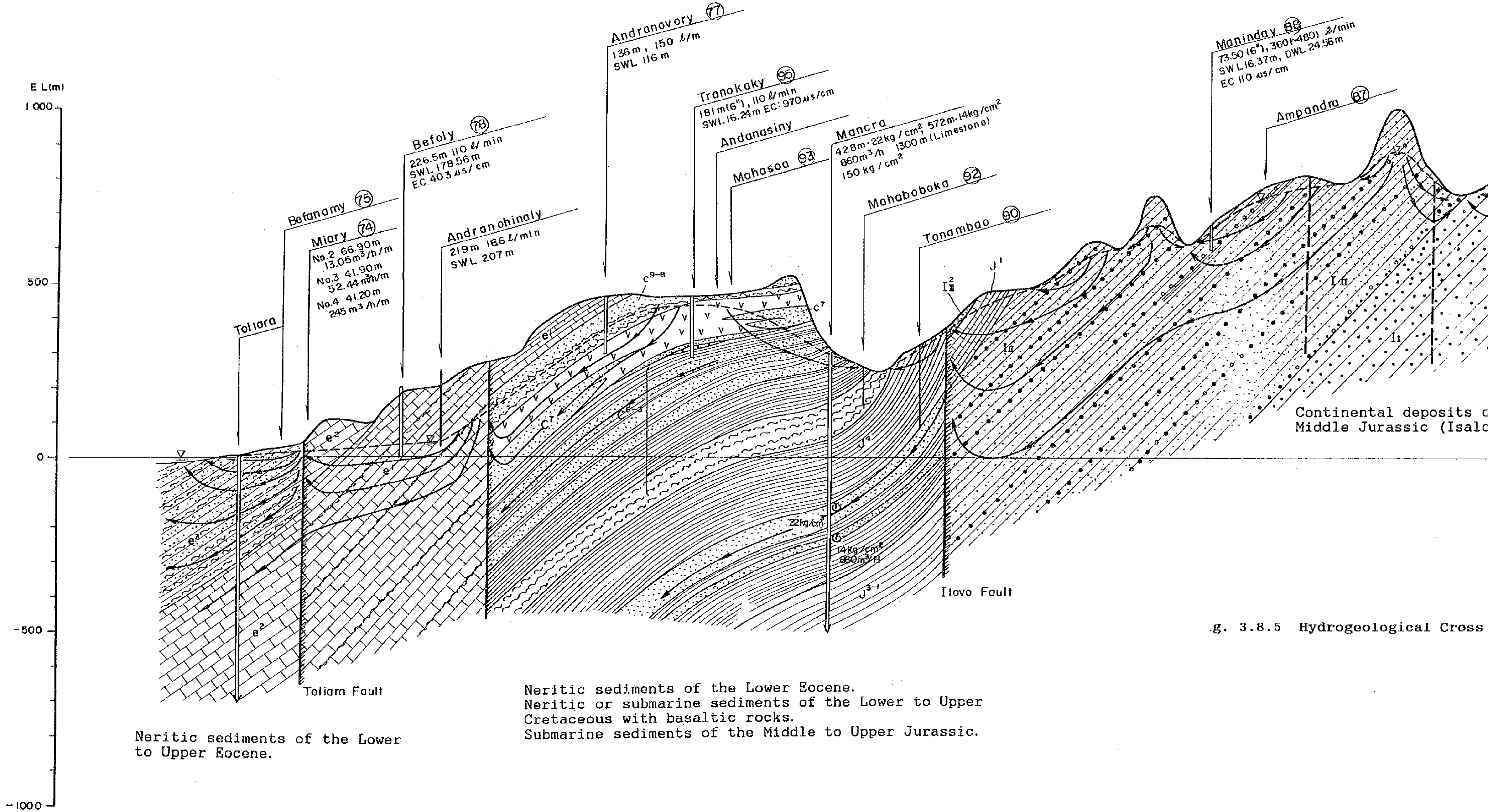
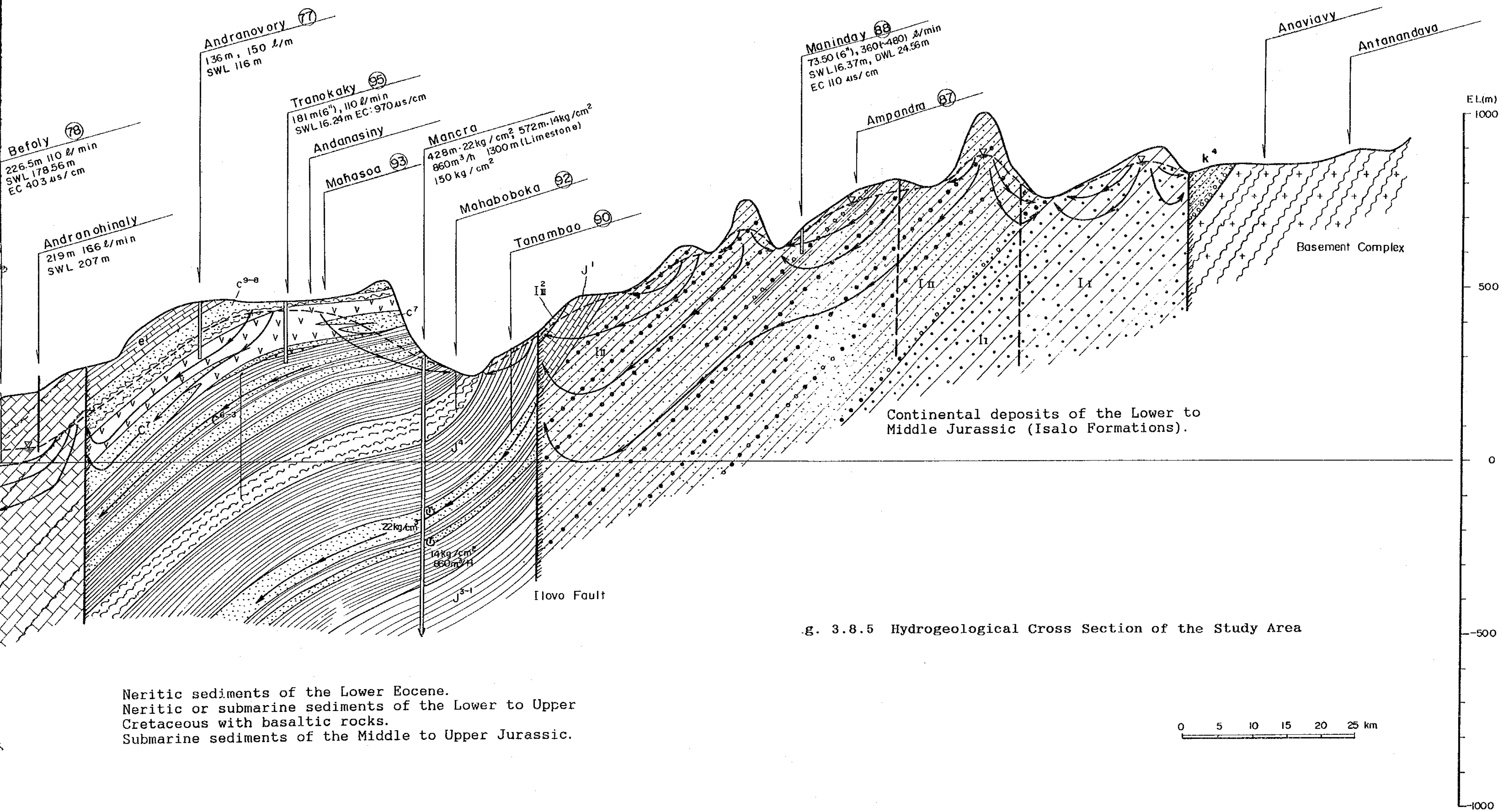


Fig. 3.8.4 Hexadiagram of Test Drilling Wells (4)



.g. 3.8.5 Hydrogeological Cross



.g. 3.8.5 Hydrogeological Cross Section of the Study Area

Neritic sediments of the Lower Eocene.
Neritic or submarine sediments of the Lower to Upper Cretaceous with basaltic rocks.
Submarine sediments of the Middle to Upper Jurassic.

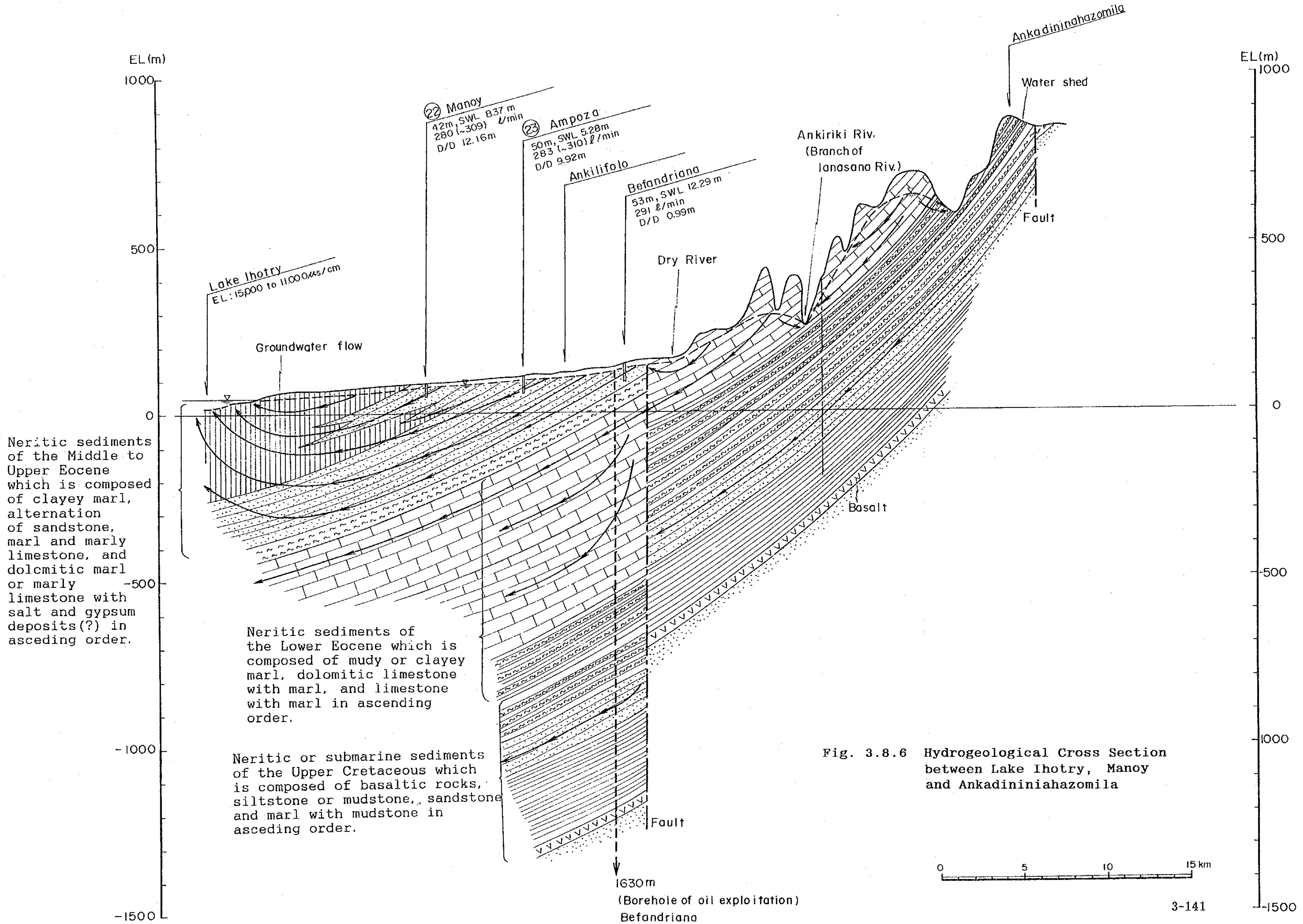


Fig. 3.8.6 Hydrogeological Cross Section between Lake Ihotry, Manoy and Ankadininiahazomila

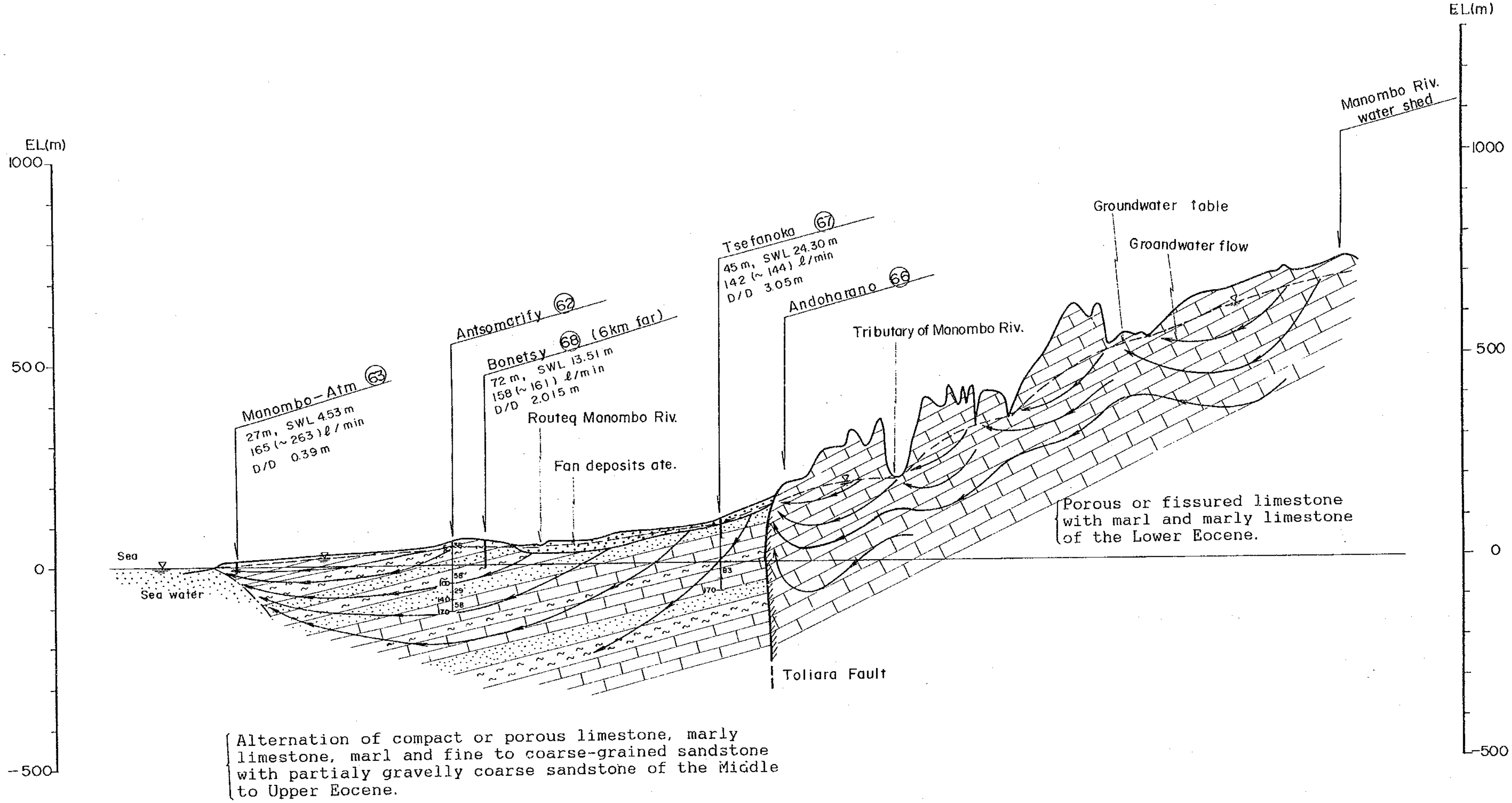


Fig. 3.8.7 Hydrogeological Cross Section of Manombo River Watershed

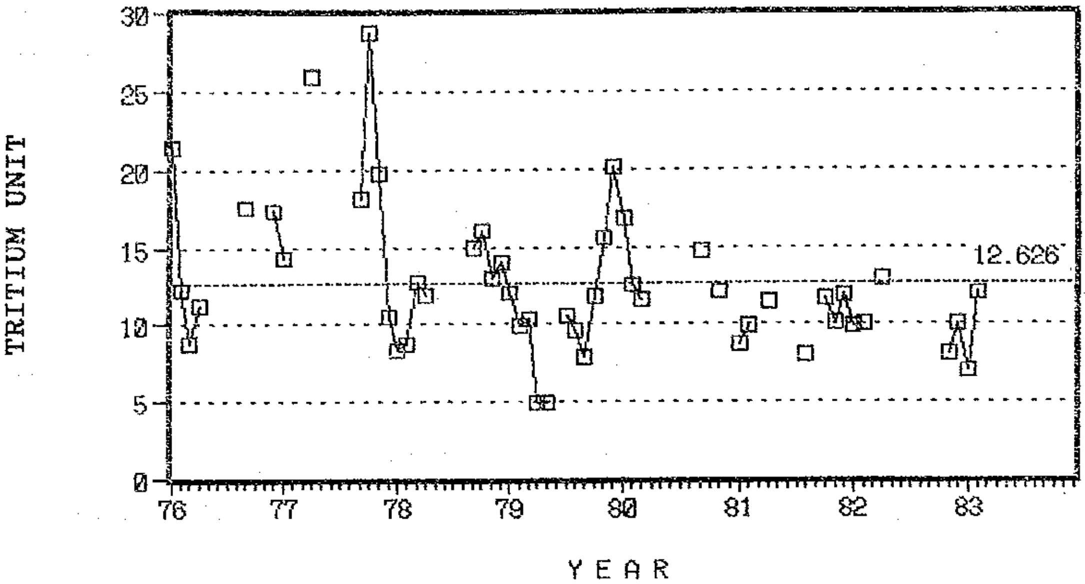
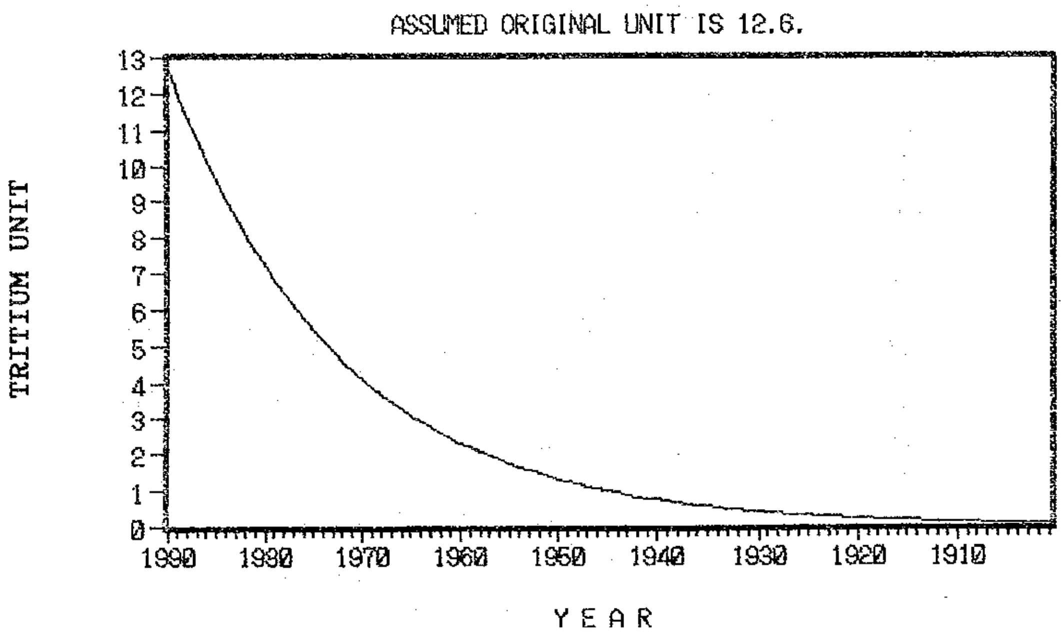


Fig. 3.8.8 Isotope Concentration in Rain at Pretoria, South Africa



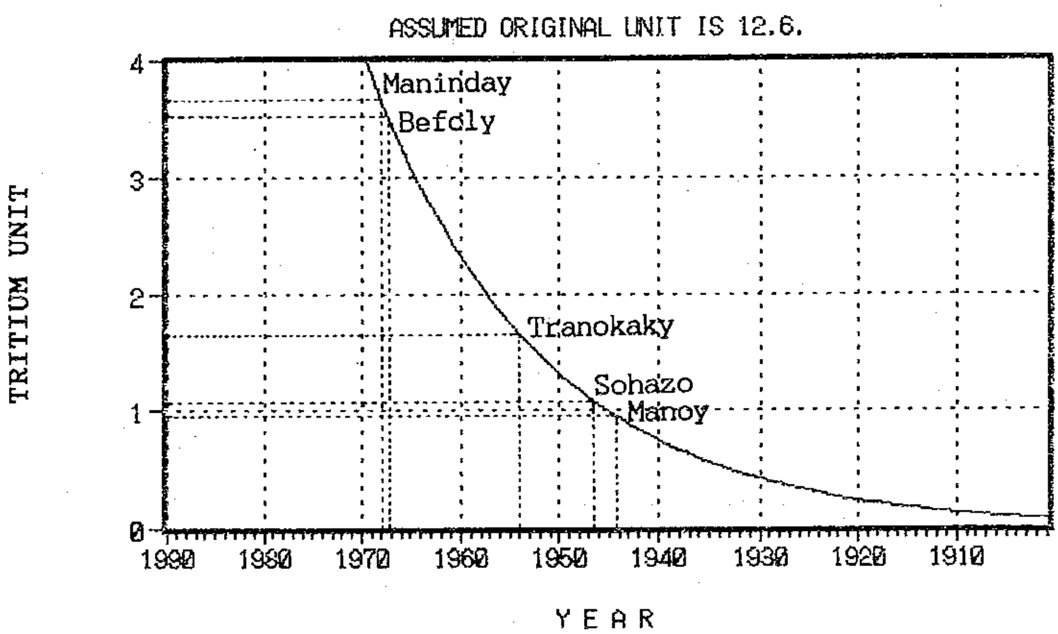


Fig. 3.8.9 Decay Curve of Tritium