CHAPTER 4

GEOPHYSICAL PROSPECTING

CHAPTER 4 GEOPHYSICAL PROSPECTING

4.1 Purpose and Methods

4.1.1 Purpose

The geophysical prospecting was carried out in the target communes except in Hanoi Province to presume subsurface geologic structures and to select test well drilling site. Because in the target communes, there was no data on subsurface geology except its shallow portion, which is limited within 20 to 30 m in depth by existing wells.

For the target communes located in shallow basement rock areas, it is important to detect faults or fractured zones where groundwater occurs. It is also useful to identify the depth to basement rock for all the communes. Further, it may be possible to presume facies of basement rock from their resistivity values.

In the Study, following three (3) kinds of geophysical prospecting were employed:

- Vertical Electric Sounding (VES) method
- Resistivity Image Profiling (RIP) method
- Very Low Frequency (VLF) method

4.1.2 Methods

(1) Vertical Electric Sounding (VES)

Vertical Electric Survey (VES) is one-dimensional electric prospecting. The vertical electric prospecting can be applied in case that underground has an approximately horizontally layered structure. Electric potentials are measured by the Schlumberger electrode array shown in Figure 4.1.1.

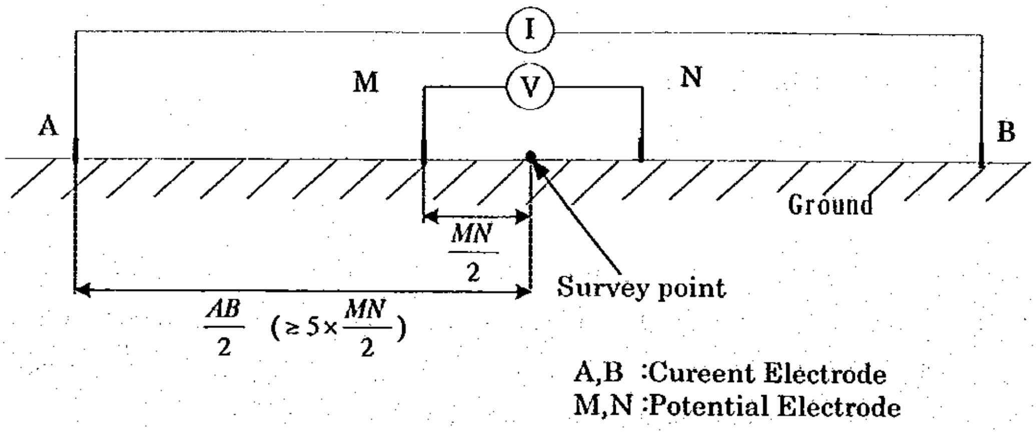


Figure 4.1.1 Schematic Diagram of Schlumberger Electrode Array

At first, two pairs of electrodes, which are current electrodes (A, B) and potential ones (M, N), set on the ground making measurement point into center. The current electrode injects a current into the ground, and the potential electrode measures the electric potential. Next, pair of electrodes spread making measurement point into center. The distance between A and B are maintained at least five times than the distance between M and N. The more current electrode spread, the deeper electric potential can be obtained. In this prospecting, the maximum distance of AB/2 was set as 200 m.

For analyzing the field data, the automatic inversion technique was employed. The flow chart of the automatic inversion is shown in Figure 4.1.2. This is based on an iterative method. At first, an apparent resistivity pseudo-section is calculated from the corrected data by the following equation:

$$\rho_a = \pi \frac{AB^2 - MN^2}{4MN}\frac{V}{I}, AB \geq 5MN$$

This pseudo-section is usually used as the initial model for the inversion. If the pseudo-section does not produce adequate convergence, an average model is used for the initial model. Next, theoretical potential data corresponding to the model are computed. Alternatively, if the underground has an approximately horizontally layered structure, the digital linear filter method (Ghosh, 1971a,) bcan be used to conduct continuous one-dimensional inversion. After theoretical potential data are calculated, the model is modified to reduce the residuals between the theoretical data and the measured data.

When the inversion is considered to have converged, the resistivity model is displayed as a color profile that clearly shows the resistivity structure.

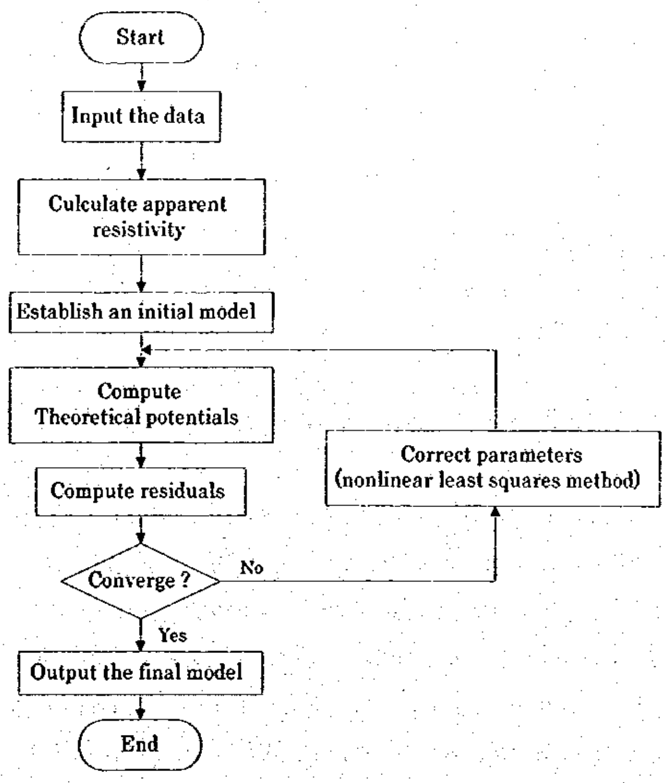


Figure 4.1.2 Flow Chart of Automatic Inversion for VES

(1) Resistivity Image Profiling (RIP)

Horizontal Electric Prospecting is one of the electric prospecting that noticing proper ground resistivity. The Resistivity Image Profiling (RIP) uses inversion techniques to analyze a two-dimensional resistivity distribution and displays the results as a colored profile. These analysis results show a more detailed and reliable resistivity distribution than VES. Electric potentials are measured by the pole-pole electrode array shown in Figure 4.1.3.

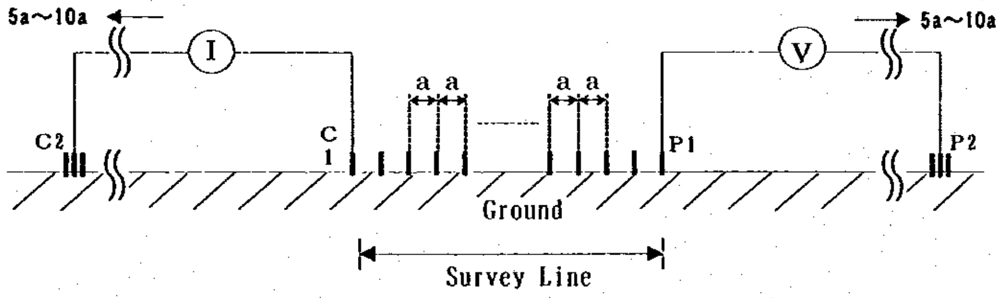


Figure 4.1.3 Schematic Diagram of Pole-Pole Electrode Array

Figure 4.1.4 shows that simple diagram of field measurement of pole-pole array. In this array, one electrode, C1, injects a current into the ground, and one electrode, P1, measures the electric potential. These two electrodes are called "moving electrodes". Another potential electrode, P2, is needed to provide a reference for the potential at P1. Electrodes C2 and P2 should be located very far from the moving electrode so that they have a negligible effect on the measurement. We call C2 and P2 "remote electrode". For actual measurement, the distance between a remote electrode and a moving electrode is maintained at least five times than the maximum distance between the moving electrodes.

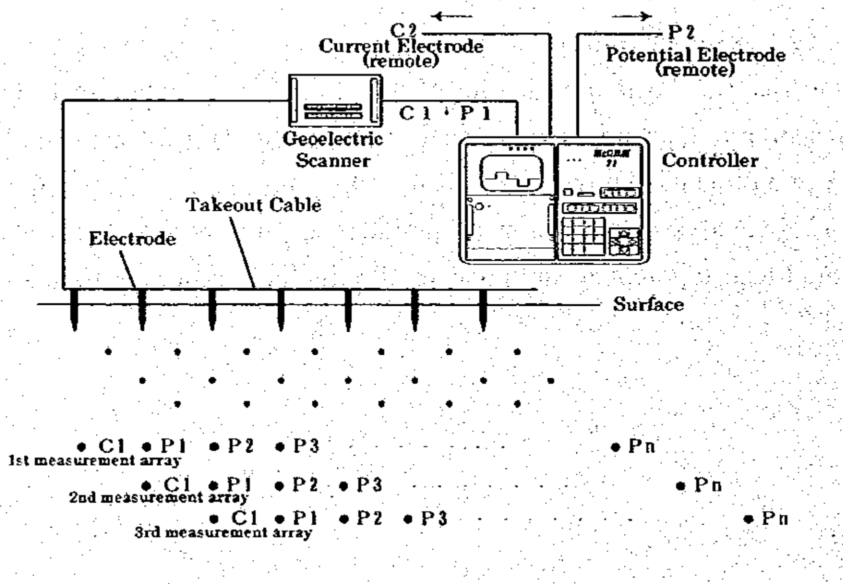


Figure 4.1.4 Schematic Diagram of Field Measurement and Its Process

The flow chart of the automatic inversion is shown in Figure 4.1.5. This is based on an iterative method. At first, terrain effects are estimated using the finite element method (Coggon, 1971). These effects then are eliminated from the measured potential data. Then, an apparent resistivity pseudo-section is produced from the corrected data. This pseudo-section is usually used as the initial model for the inversion. If the pseudo-section does not produce adequate convergence, an average model is used for the initial model.

Next, theoretical potential data corresponding to the model are computed. Alternatively, if the underground has an approximately horizontally layered structure, the digital linear filter method (Ghosh, 1971a, b) can be used to conduct the Continuous one-dimensional inversion. After theoretical potential data are calculated, the model is modified to reduce the residuals between the theoretical data and the measured data. When the inversion is considered to have converged, the resistivity model is displayed as a color profile that clearly shows the resistivity structure.

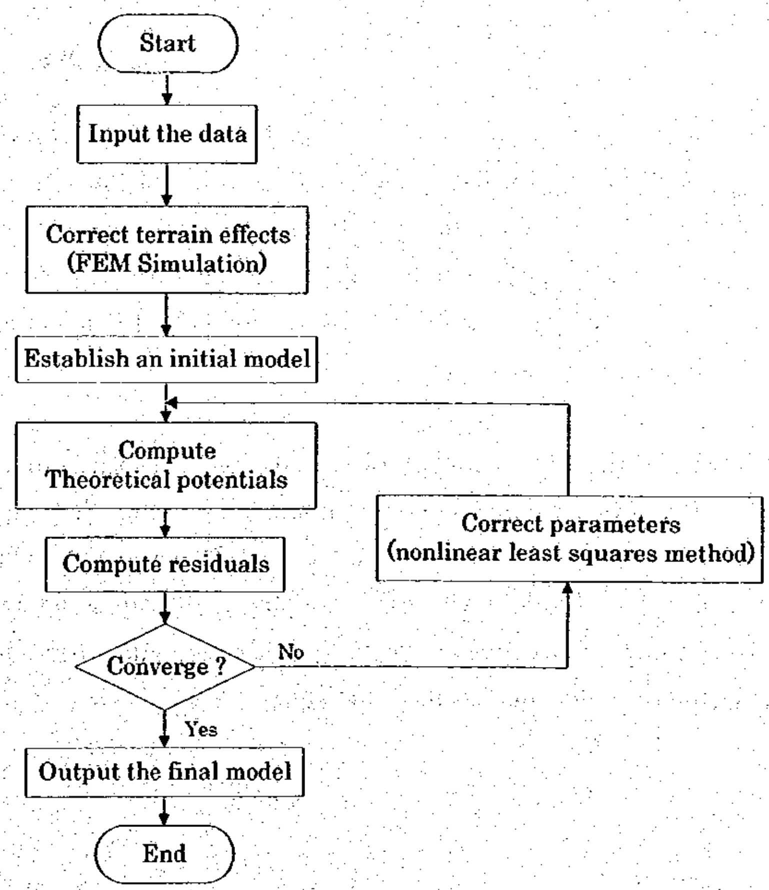


Figure 4.1.5 Flow Chart of 2-D Automatic Inversion for RIP

(2) Very Low Frequency (VLF) Method

The Very Low Frequency (VLF) method is an electromagnetic geophysical method that aims at detecting conductive or resistive zones located at depths of a few tens meters. It uses the electromagnetic carrier waves produced by military transmitters in order to communicate with submarines. Table 4.1.1 shows the location of the major transmitters in the world.

Table 4.1.1 Major Transmitter in The World

Call sign	Place	Frequency	Call sign	Place	Frequency
FUO (1)	France	15.1 kHz	NSS	U.S.A	21.4 kHz
FUO (2)	India	15.1 kHz	GBZ	England	19.6 kHz
GBR	England	16.0 kHz	ICV	Italy	20.27 kHz
FUB	French	16.8 kHz	NWC	Australia	22.3 kHz
UMS	Moscow	17.1 kHz	NPM	Hawai	23.4 kHz
JJT	Japan	22.2 kHz	LPZ	Argentino	23.6 kHz
HN	Norway	17.6 kHz	NBA	Panama	24.0 kHz
NAA	U.S.A	24.0 kHz	NLK	U.S.A	27.5 kHz

These waves —called primary fields in the VLF method— have a frequency of 15 to 30 kHz and are propagated between the surface of the earth and the ionosphere. In the presence of conductive bodies, the primary field induces secondary currents inside, and these currents generate a secondary field. Thus, the measurement of the total field (primary1secondary) at the surface of the earth can help in detecting conductive structures located in the prospective area.

Figure 4.2.8 shows the tilt angle anomaly observed along a profile crossing a vertical conductive dyke. It can be seen that a maximum and a minimum tilt angle separated by an inflexion point located above the top of the dyke. In case of the applying highly conductive structures, the ellipticity value is less than the tilt value and has an opposite sign. In poorly conductive structures or geological contacts, the ellipticity value is of the same order as the tilt value and has the same sign.

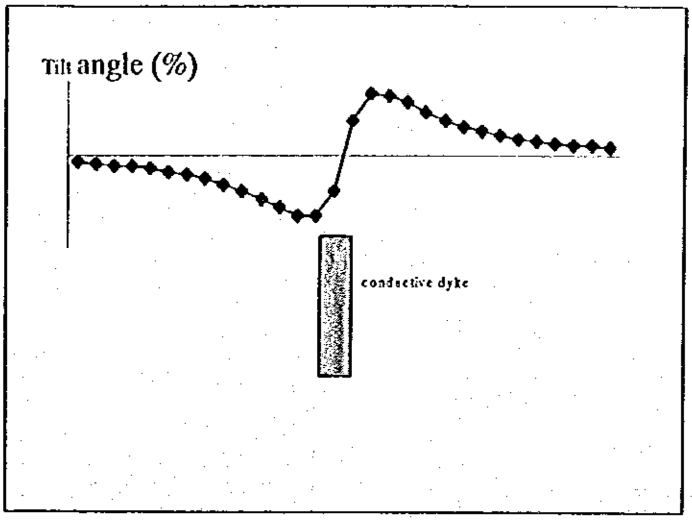


Figure 4.1.8 Example of VLF Tilt Angle Anomaly for A Thin Vertical Conductive Dyke

4.2 Interpretation of Result

4.2.1 Amount of Geophysical Prospecting

The field survey of geophysical prospecting was carried out during a period from November 1998 until January 1999. Table 4.2.1 summarizes the amount of geophysical prospecting carried out by the Study Team.

The locations of the geophysical prospecting were decided based on the results of filed hydrogeological investigations. The locations of VES and locations and orientations of RIP and VLF were carefully selected to investigate subsurface geologic structures efficiently.

Figures 4.2.1 to 4.2.12 show the locations of geophysical prospecting with the locations of the test wells and the investigated existing wells in the target communes. Total numbers of VES, RIP, and VLF prospecting are 212, 15, and 18, respectively.

Table 4.2.1 Amount of Geophysical Prospecting

Province	Commune	VES	RIP			VLF	
		Nos.	Nos.	Length (m)	Depth (m)	Nos.	Length (m)
Ha Tinh	Duc Yen	9	1	300	150	0	-
	Yen HO	7	0	-	-	0	-
	Trung Le	7	1	300	150	0	-
	Bui Xa	12	0	-	-	0	-
Thanh Hoa	Nong Cong Town	3	0	-	-	0	-
	Van Thang	13	1	600	150	0	-
	Thieu Hung	13	1	470	200	0	-
	Thieu Do	10	2	600	150	0	-
	Dinh Tuong	7	0	-	-	0	-
	Vinh Thanh	12	1	600	150	2	600 620
	Vinh Loc Town	3	0	-	-	0	-
Ninh Vinh	Quang Son	27	2	600	150	1	760
	Yen Thang	18	1	600	150	4	670 350 550 550
	Dong Phong	12	1	600	150	2	590 640
Thai Nguyen	Dong Bam	5	1	600	150	2	650 800
	Hoa Thuong	18	1	600	150	2	600 740
	Nam Tien	13	1	600	150	3	660 600 670
	Thinh Duc	23	1	600	150	2	410 600
Total		212	15	4200	4200		2800

4.2.2 Interpretation

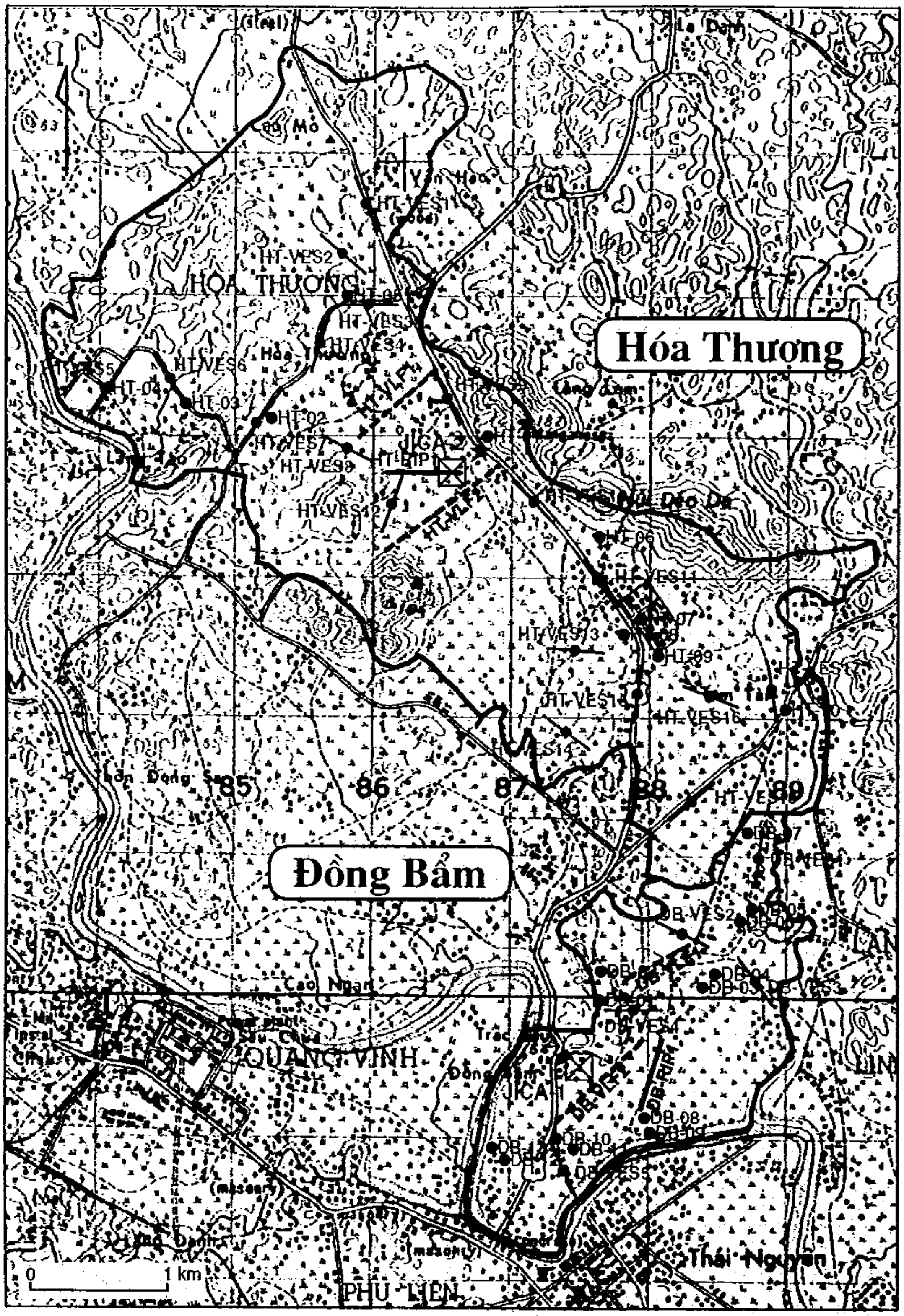
The subsurface geologic structures were interpreted based on the vertical resistivity distributions by VES, the detailed resistivity profiles by RIP, and occurrence of anomalies by VLF prospecting. The detailed results of VES, RIP, and VLF prospecting are presented in the

Data Report.

Figure 4.2.23 shows the results of geophysical prospecting at Dong Bam and Hoa Thuong Communes in Thai Nguyen Province. It is revealed that the resistivity of basement rock is low in northeast of Hoa Thuong Commune and high in southwest. In southwest of Dong Bam Commune, the resistivity of basement rock is low. Therefore, it is understood that there is a high resistivity zone having NW-SE direction in the area. The RIP surveys were carried out at the boundaries of high resistivity zone and low resistivity zone in both the communes. According to the RIP results, it is found that the resistivity of basement rock sharply changes in narrow areas. The VLF survey carried at Dong Bam Commune with NNE-SSW orientation detected a clear anomaly at the place where the resistivity of basement rock is sharply changed. With the results of field hydrogeological investigations, it was interpreted that the high resistivity zone having NW-SE direction would be limestone, whereas the low resistivity zone would be sandstone and shale. The boundaries of high resistivity zone and low resistivity zone was presumed as fault fractured zones. From the results, the locations of JICA-1 and JICA-2 test wells were located at the limestone side of the fault fractured zones. As a result, the test wells encountered fractured limestone with caves and yielded more than 1,000 m^3/day of groundwater successfully.

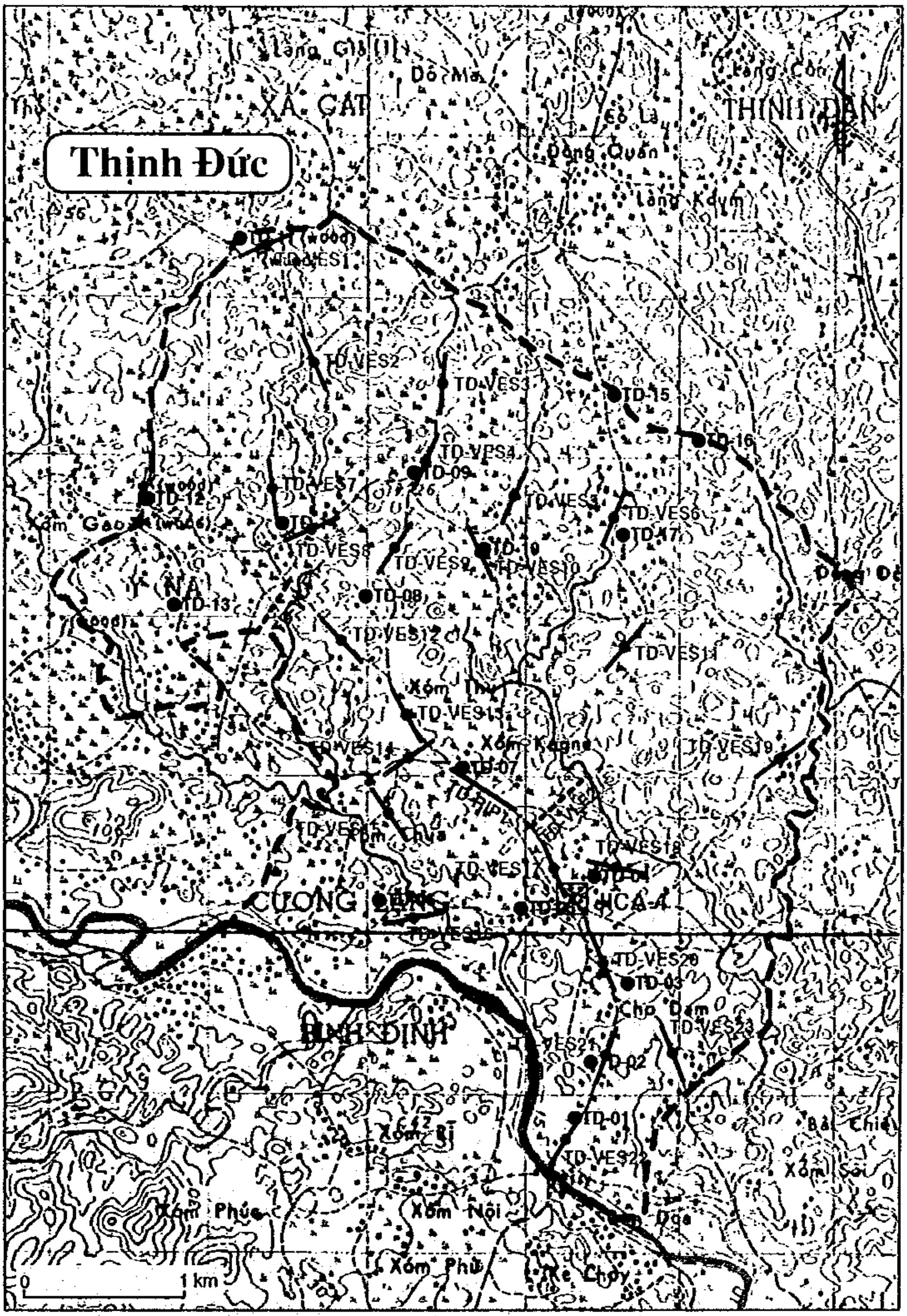
Figures 4.2.14 to 4.2.29 show the summarized results of VES surveys at the target communes. The sudden changes in resistivity of basement rocks were found in Quang Son and Dong Phong Communes of Ninh Binh Province, Vinh Thanh and Thieu Hung Communes in Thanh Hoa Province. The VLF surveys detected anomalies in basement rock in Thinh Duc and Nam Tien Communes in Thai Nguyen Province, and Yen Thang, Quang Son, and Dong Phong Communes in Ninh Binh Province.

In the target communes in Ha Tinh Province, the resistivity values even in deeper portion (60 to 100 m depth) were low, ranging from 20 to 60 ς-m. Before drilling the test wells, it was presumed that the subsurface geology consisted of fine sediments or electric conductivity of groundwater was high. The results of test well drillings revealed that the basement rock consists of weakly consolidated Neogene clay and the electric conductivity of groundwater in both shallow zone and deep zone is high.



● DB-01 Measured Well with No.
—●— Vertical Prospecting (AB/2=200m) [400m]
——— Horizontal Prospecting (L=300m) [500m]
- - - - VLF-EM Prospecting (L=500m) [500m]
⊠ JICA Test Well

Figure 4.2.1	Location of Geophysical Prospecting in Hóa Thượng and Đồng Bẩm Communes, Thái Nguyên Province
THE STUDY ON GROUNDWATER DEVELOPMENT IN THE RURAL PROVINCES OF NORTHERN PART IN THE SOCIALIST REPUBLIC OF VIETNAM	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	



●TD-01 Investigated Existing Well with No.

Vertical Prospecting (AB/2=200m) [400m]

Horizontal Prospecting (L=300m) [500m]

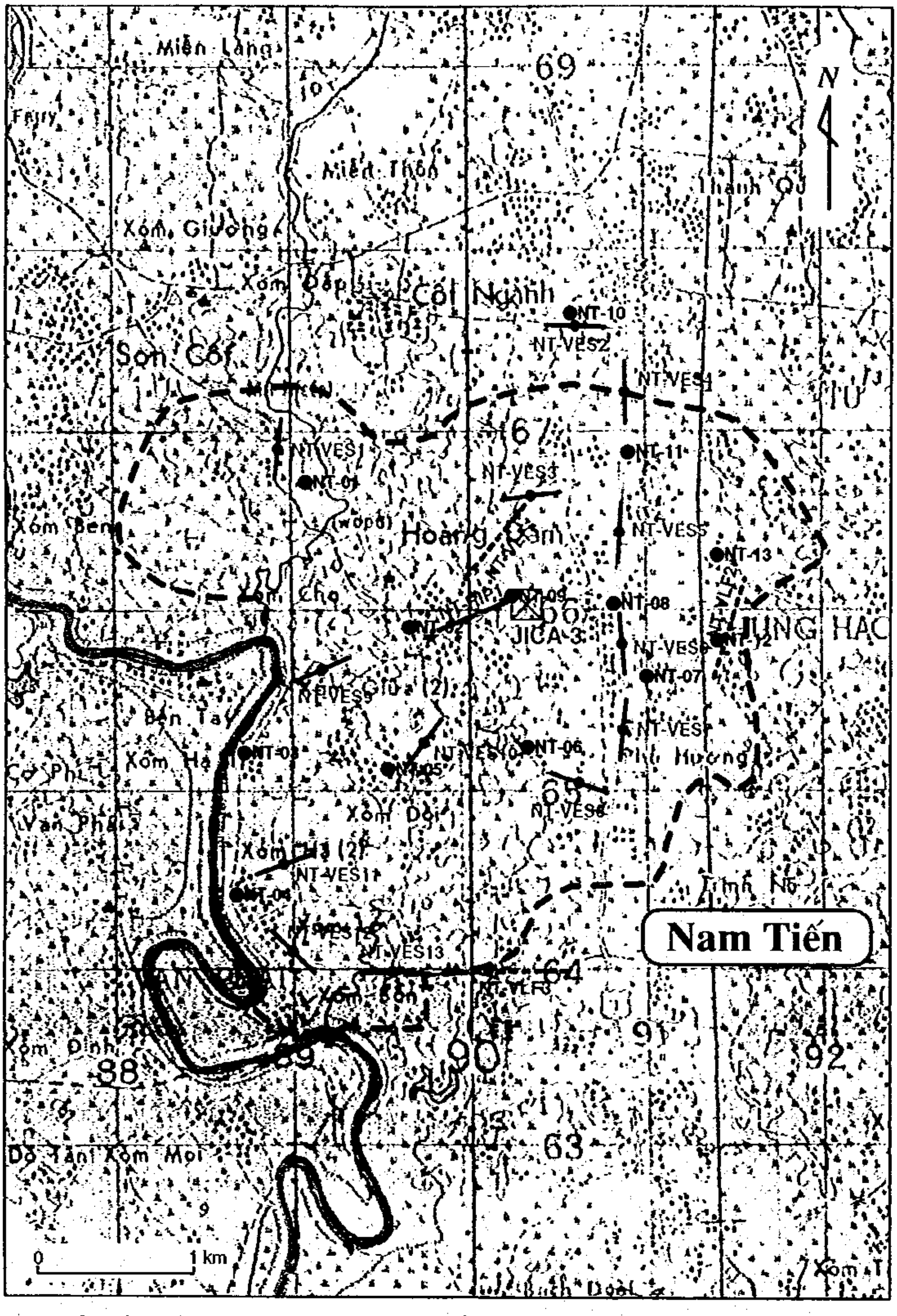
VLF-EM Prospecting (L=500m) [500m]

☒ JICA Test Well

Figure 4.2.2	Location of Geophysical Prospecting in Thịnh Đức Commune, Thái Nguyên Province

THE STUDY ON GROUNDWATER DEVELOPMENT IN THE RURAL PROVINCES OF NORTHERN PART IN THE SOCIALIST REPUBLIC OF VIETNAM

JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)



● NT-01 Investigated Existing Well with No.

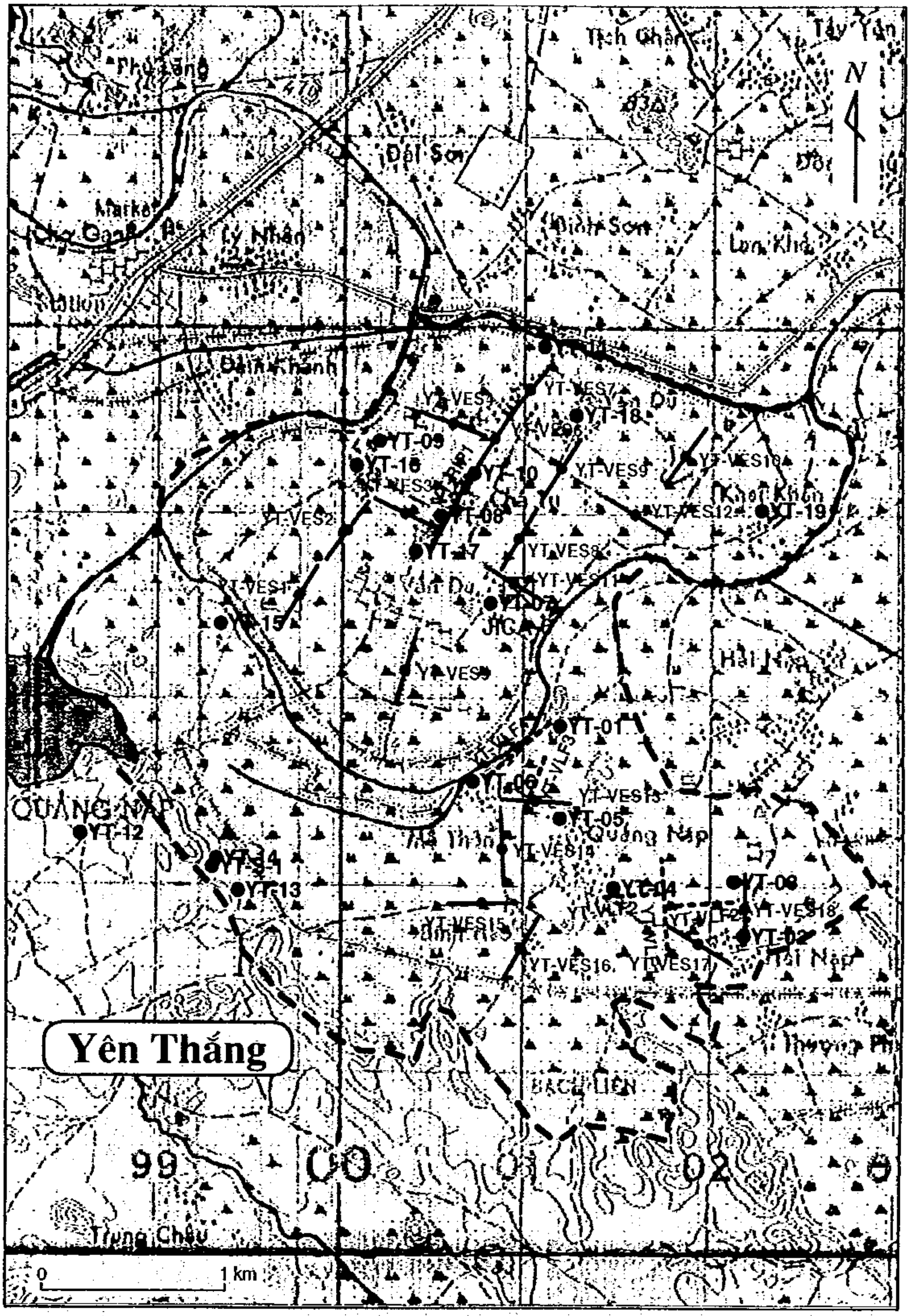
Vertical Prospecting (AB/2=200m) [400m]

Horizontal Prospecting (L=300m) [500m]

VLF-EM Prospecting (L=500m) [500m]

JICA Test Well

Figure 4.2.3	Location of Geophysical Prospecting in Nam Tiến Commune, Thái Nguyên Province
THE STUDY ON GROUNDWATER DEVELOPMENT IN THE RURAL PROVINCES OF NORTHERN PART IN THE SOCIALIST REPUBLIC OF VIETNAM	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	

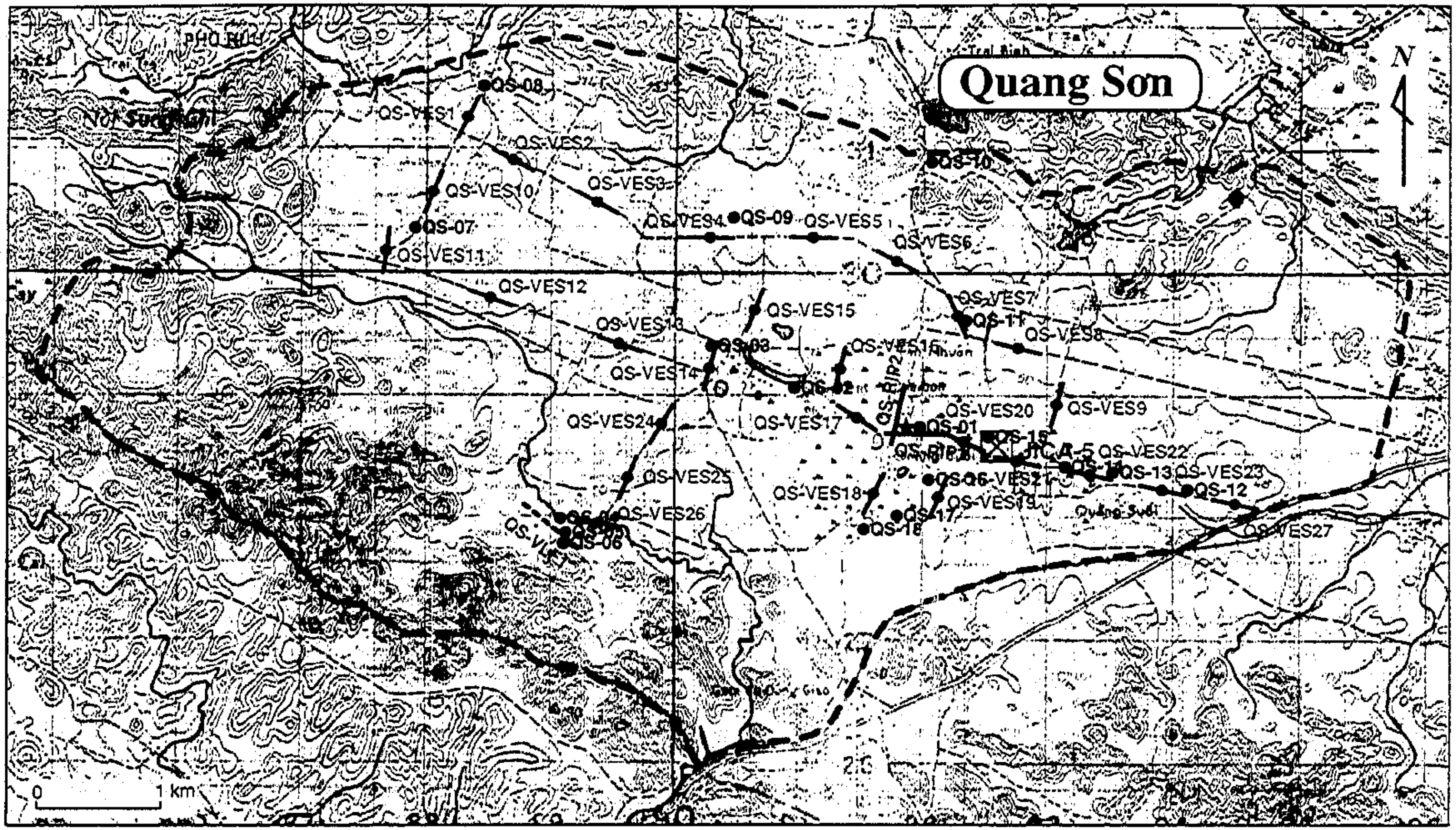


●YT-01	Investigated Existing Well with No.
—●—	Vertical Prospecting (AB/2=200m) [400m]
——	Horizontal Prospecting (L=300m) [500m]
- - - -	VLF-EM Prospecting (L=500m) [500m]
⊠	JICA Test Well

Figure 4.2.4 Location of Geophysical Prospecting in Yên Thắng Commune, Ninh Bình Province

THE STUDY ON GROUNDWATER DEVELOPMENT IN THE RURAL PROVINCES OF NORTHERN PART IN THE SOCIALIST REPUBLIC OF VIETNAM

JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)



● QS-01	Investigated Existing Well with No.
—●—	Vertical Prospecting (AB/2=200m) [400m]
——	Horizontal Prospecting (L=300m) [500m]
-----	VLF-EM Prospecting (L=500m) [500m]
☒	JICA Test Well

Figure 4.2.5	Location of Geophysical Prospecting in Quang Son Commune, Ninh Bình Province

THE STUDY ON GROUNDWATER DEVELOPMENT IN THE RURAL PROVINCES OF NORTHERN PART IN THE SOCIALIST REPUBLIC OF VIETNAM

JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)

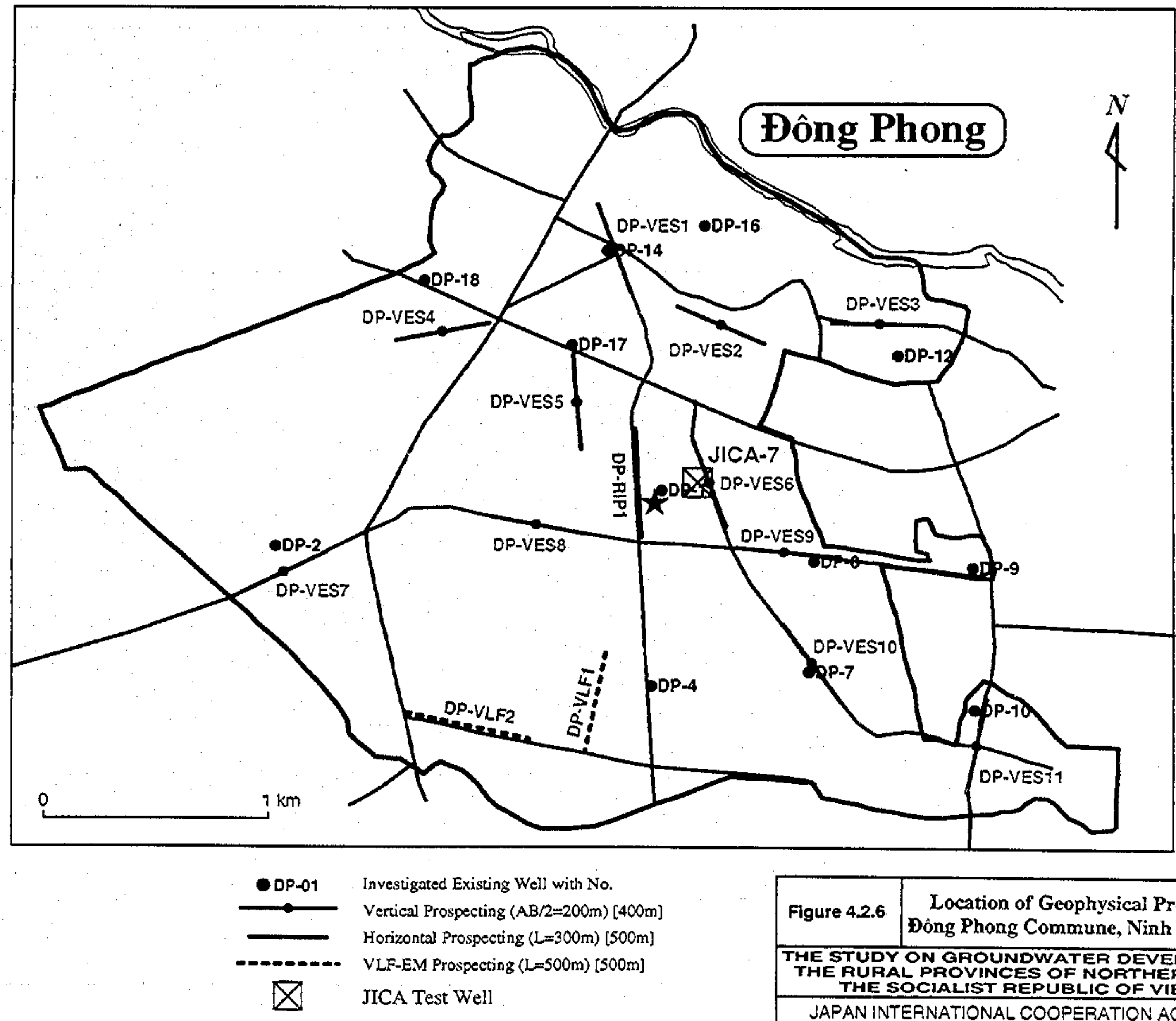
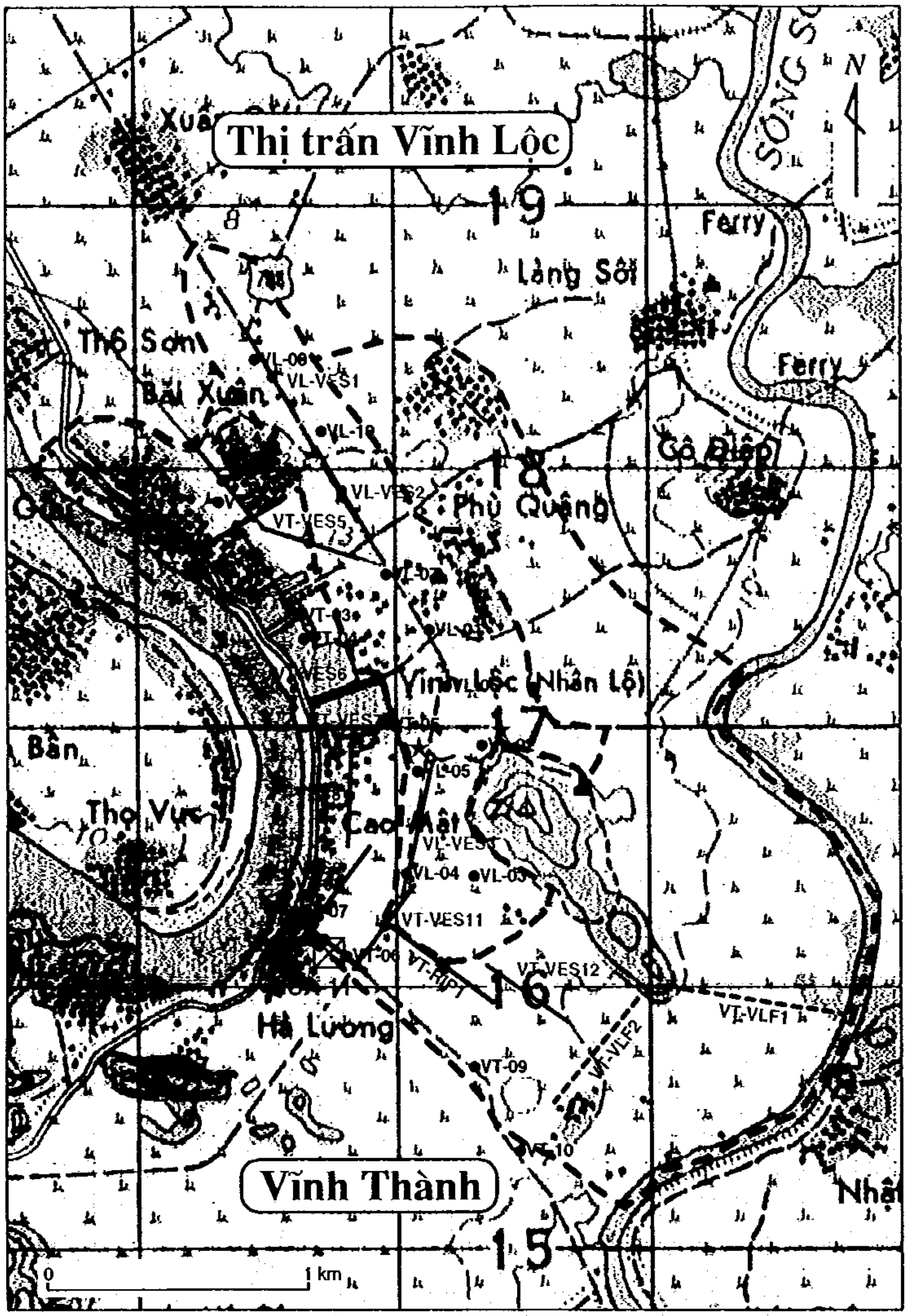
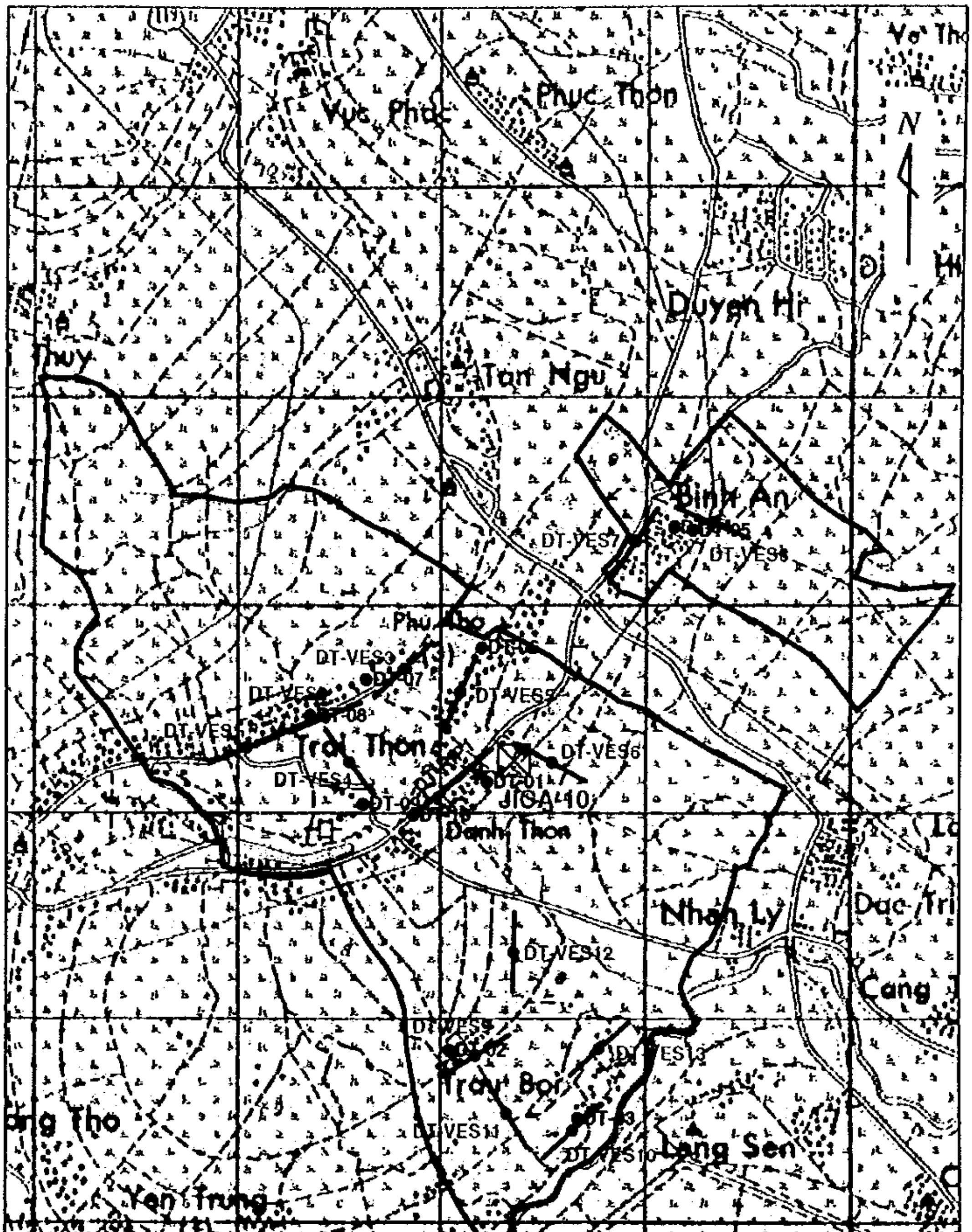


Figure 4.2.6	Location of Geophysical Prospecting in Đông Phong Commune, Ninh Bình Province
THE STUDY ON GROUNDWATER DEVELOPMENT IN THE RURAL PROVINCES OF NORTHERN PART IN THE SOCIALIST REPUBLIC OF VIETNAM	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	



● VL-01	Investigated Existing Well with No.
——◆——	Vertical Prospecting (AB/2=200m) [400m]
————	Horizontal Prospecting (L=300m) [500m]
- - - - - - - -	VLF-EM Prospecting (L=500m) [500m]
⊠	JICA Test Well

Figure 4.2.7	Location of Geophysical Prospecting in Thị trấn Vĩnh Lộc and Vĩnh Thành Communes, Thanh Hóa Province
THE STUDY ON GROUNDWATER DEVELOPMENT IN THE RURAL PROVINCES OF NORTHERN PART IN THE SOCIALIST REPUBLIC OF VIETNAM	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	



● DT-01 Measured Well with No.

Vertical Prospecting (AB/2=200m) [400m]

Horizontal Prospecting (L=300m) [500m]

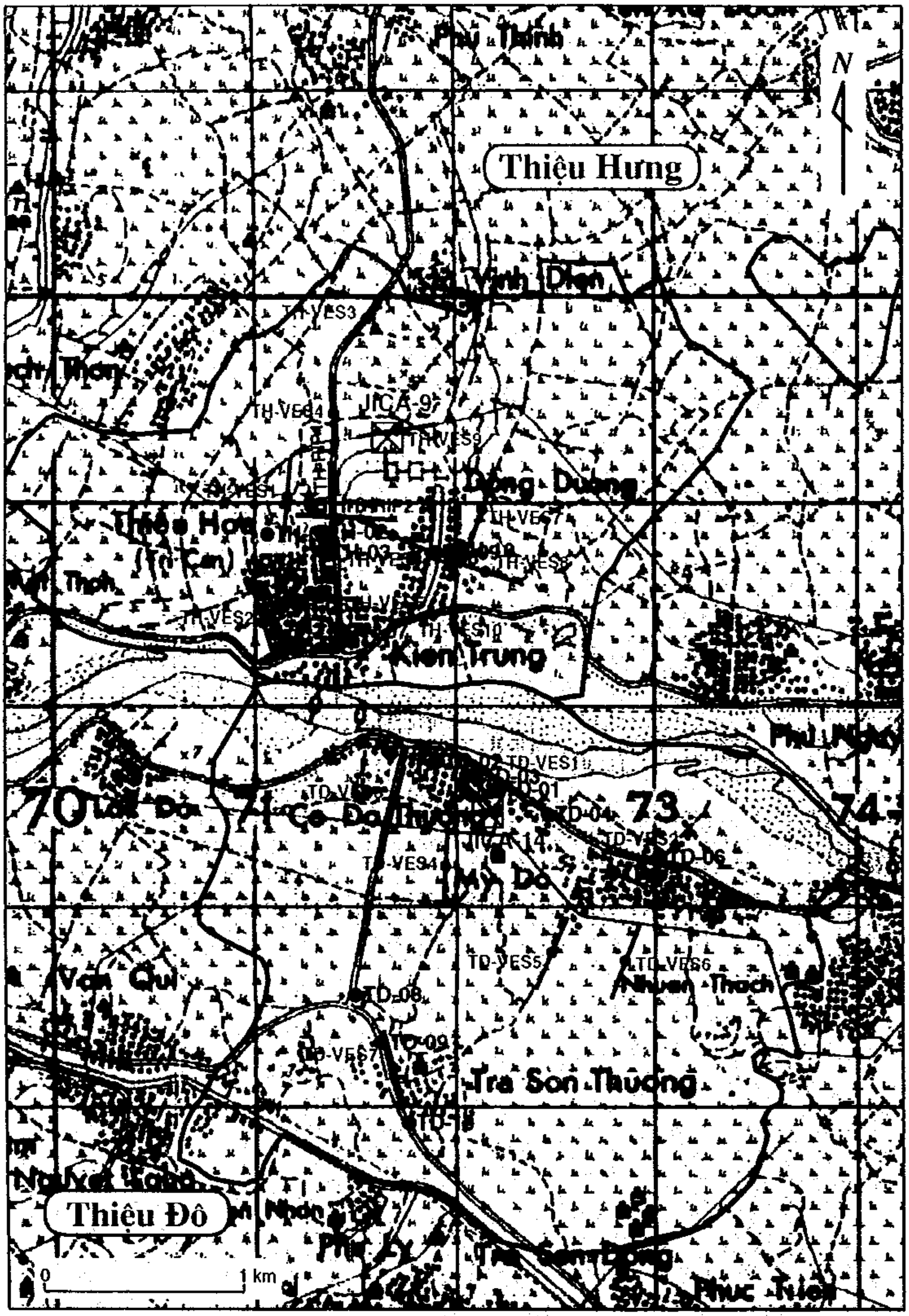
VLF-EM Prospecting (L=500m) [500m]

☒ JICA Test Well

Figure 4.2.8	Location of Geophysical Prospecting in Định Tường Commune, Thanh Hóa Province

THE STUDY ON GROUNDWATER DEVELOPMENT IN THE RURAL PROVINCES OF NORTHERN PART IN THE SOCIALIST REPUBLIC OF VIETNAM

JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)



● TH-01 Investigated Existing Well with No.
Vertical Prospecting (AB/2=200m) [400m]
Horizontal Prospecting (L=300m) [500m]
VLF-EM Prospecting (L=500m) [500m]
☒ JICA Test Well

Figure 4.2.9	Location of Geophysical Prospecting in Thiệu Hưng and Thiệu Đô Communes, Thanh Hóa Province

THE STUDY ON GROUNDWATER DEVELOPMENT IN THE RURAL PROVINCES OF NORTHERN PART IN THE SOCIALIST REPUBLIC OF VIETNAM

JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)

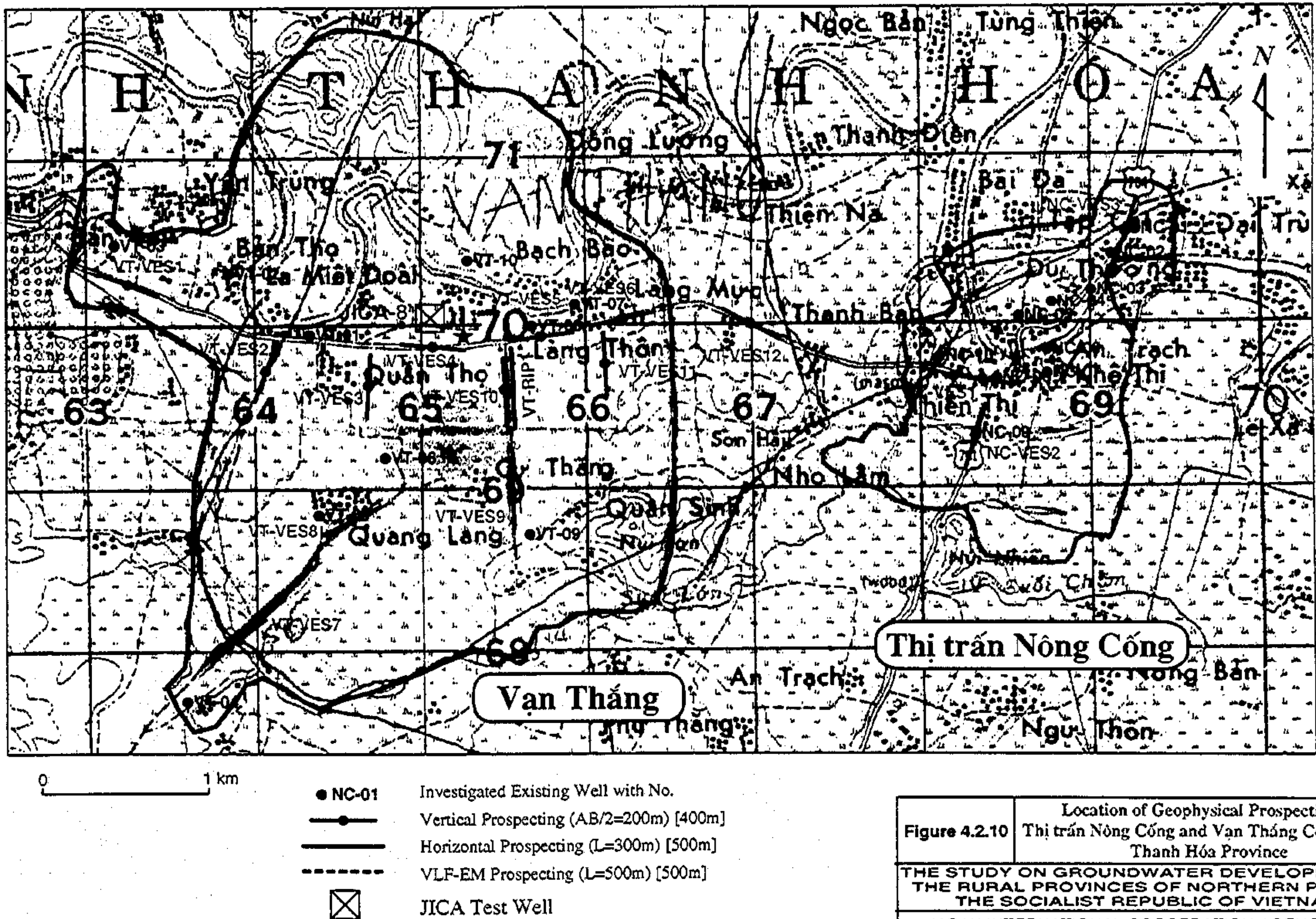
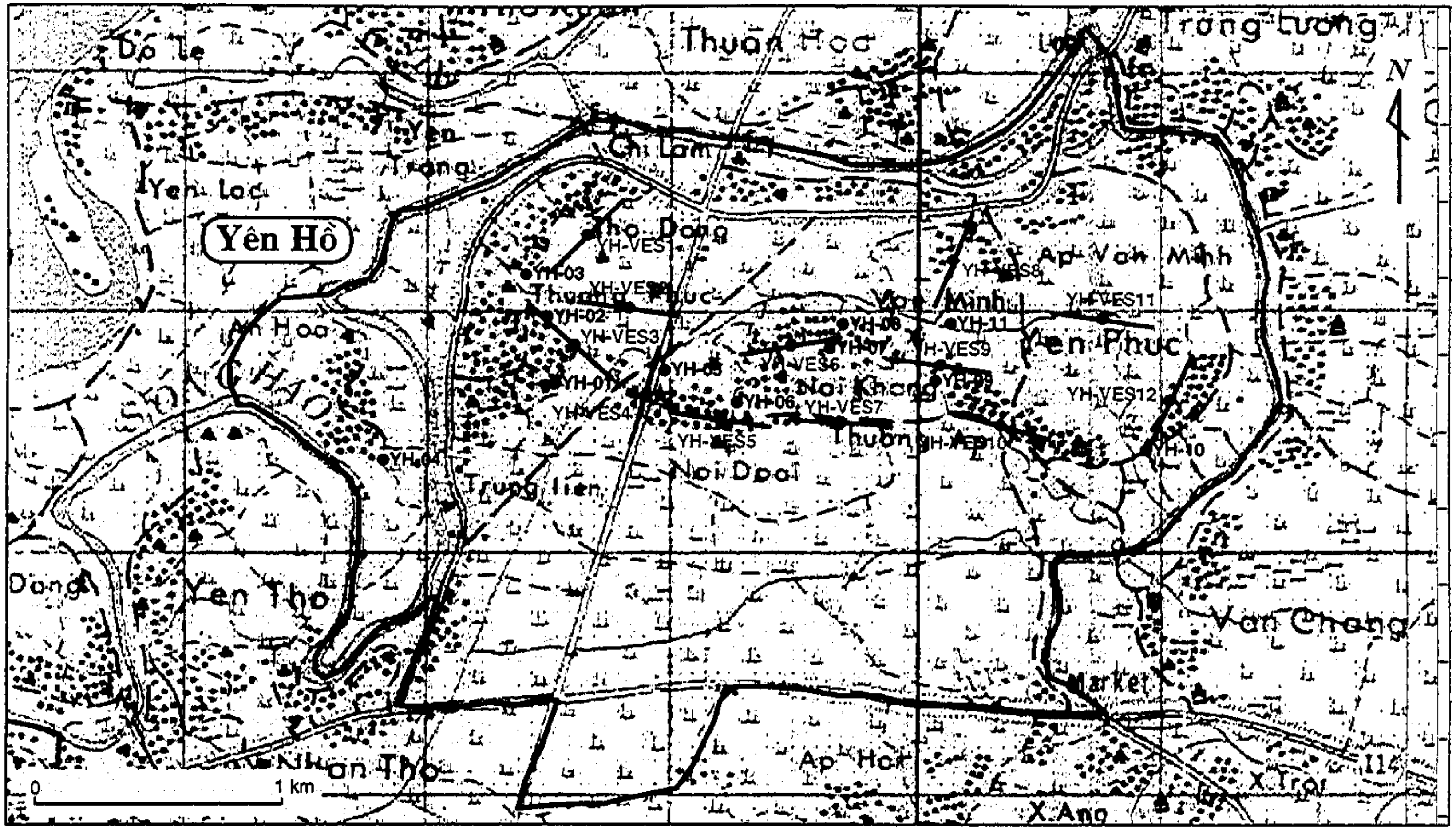


Figure 4.2.10	Location of Geophysical Prospecting in Thị trấn Nông Cống and Van Thắng Communes, Thanh Hóa Province

THE STUDY ON GROUNDWATER DEVELOPMENT IN THE RURAL PROVINCES OF NORTHERN PART IN THE SOCIALIST REPUBLIC OF VIETNAM

JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)



● YH-01 Investigated Existing Well with No.

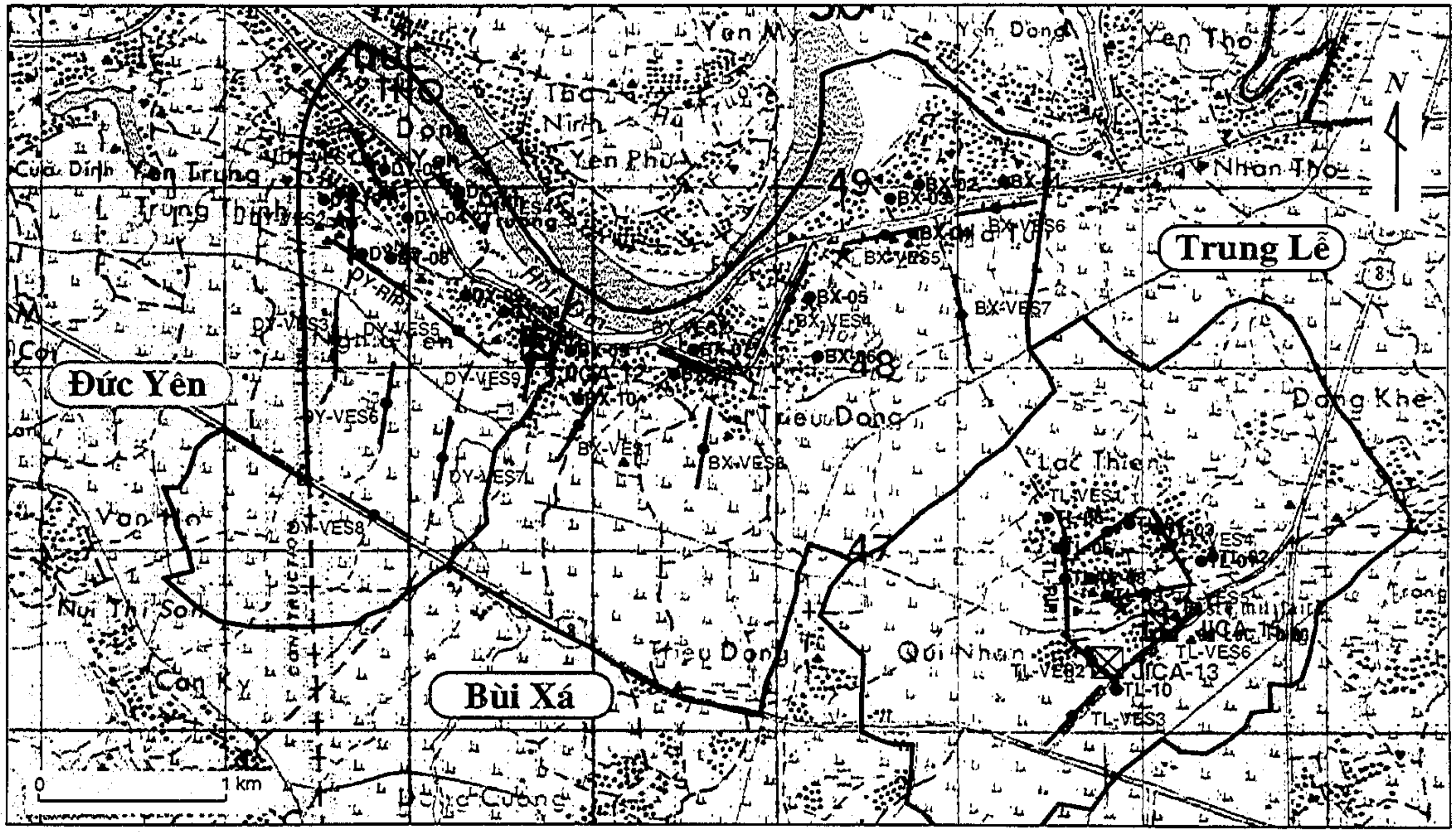
Vertical Prospecting (AB/2=200m) [400m]

Horizontal Prospecting (L=300m) [500m]

VLF-EM Prospecting (L=500m) [500m]

☒ JICA Test Well

Figure 4.2.11	Location of Geophysical Prospecting in Yên Hồ Commune, Hà Tĩnh Province
THE STUDY ON GROUNDWATER DEVELOPMENT IN THE RURAL PROVINCES OF NORTHERN PART IN THE SOCIALIST REPUBLIC OF VIETNAM	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	



● TL-01 Investigated Existing Well with No.

Vertical Prospecting (AB/2=200m) [400m]

Horizontal Prospecting (L=300m) [500m]

VLF-EM Prospecting (L=500m) [500m]

⊠ JICA Test Well

Figure 4.2.12 Location of Geophysical Prospecting in Đức Yên, Bùi Xá and Trung Lễ Communes, Hà Tĩnh Province

THE STUDY ON GROUNDWATER DEVELOPMENT IN THE RURAL PROVINCES OF NORTHERN PART IN THE SOCIALIST REPUBLIC OF VIETNAM

JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)

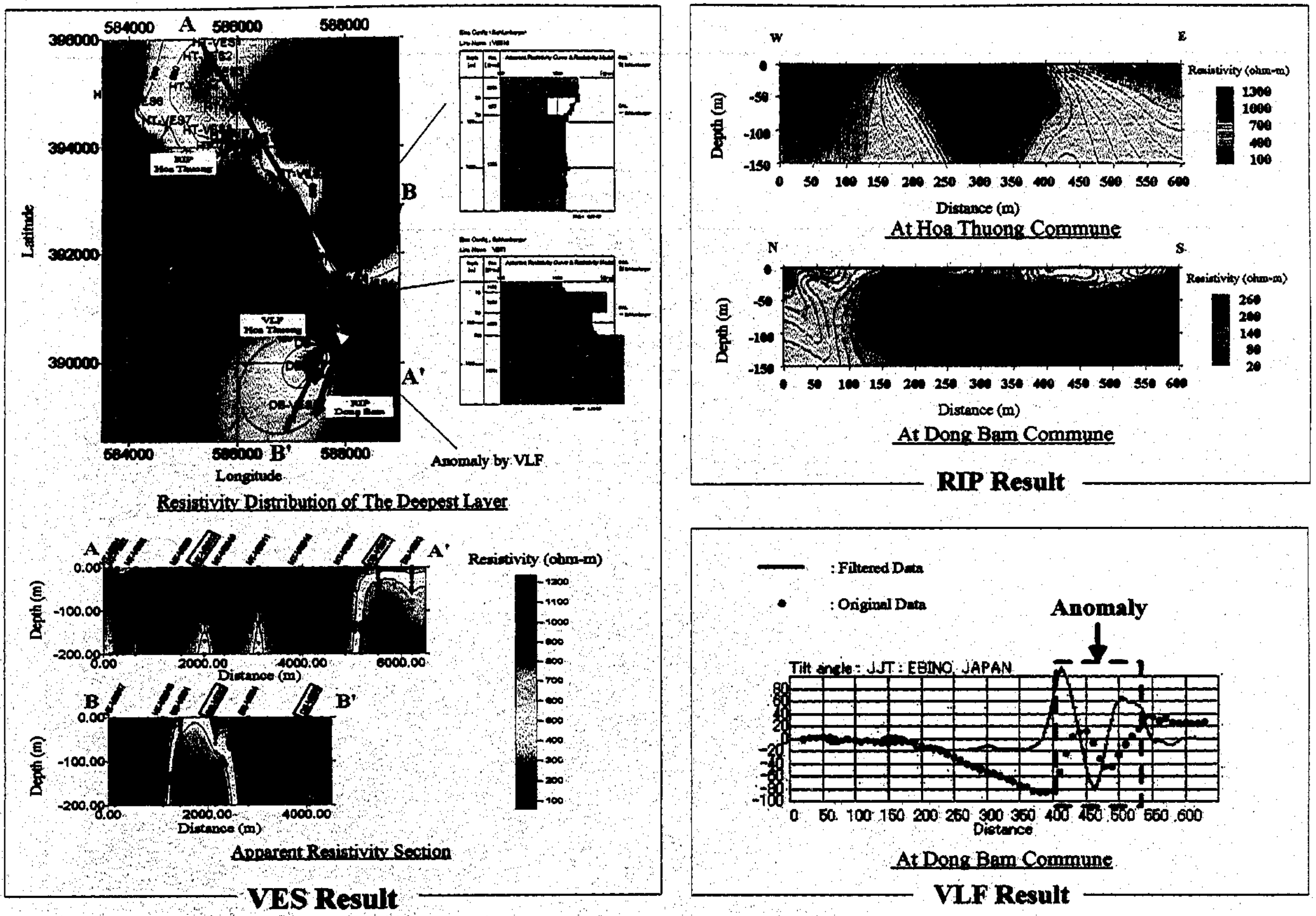


Figure 4.2.13 The Result of Geophysical Survey at Dong Bam and Hoa Thuong Commune in Thai Nguyen Province.

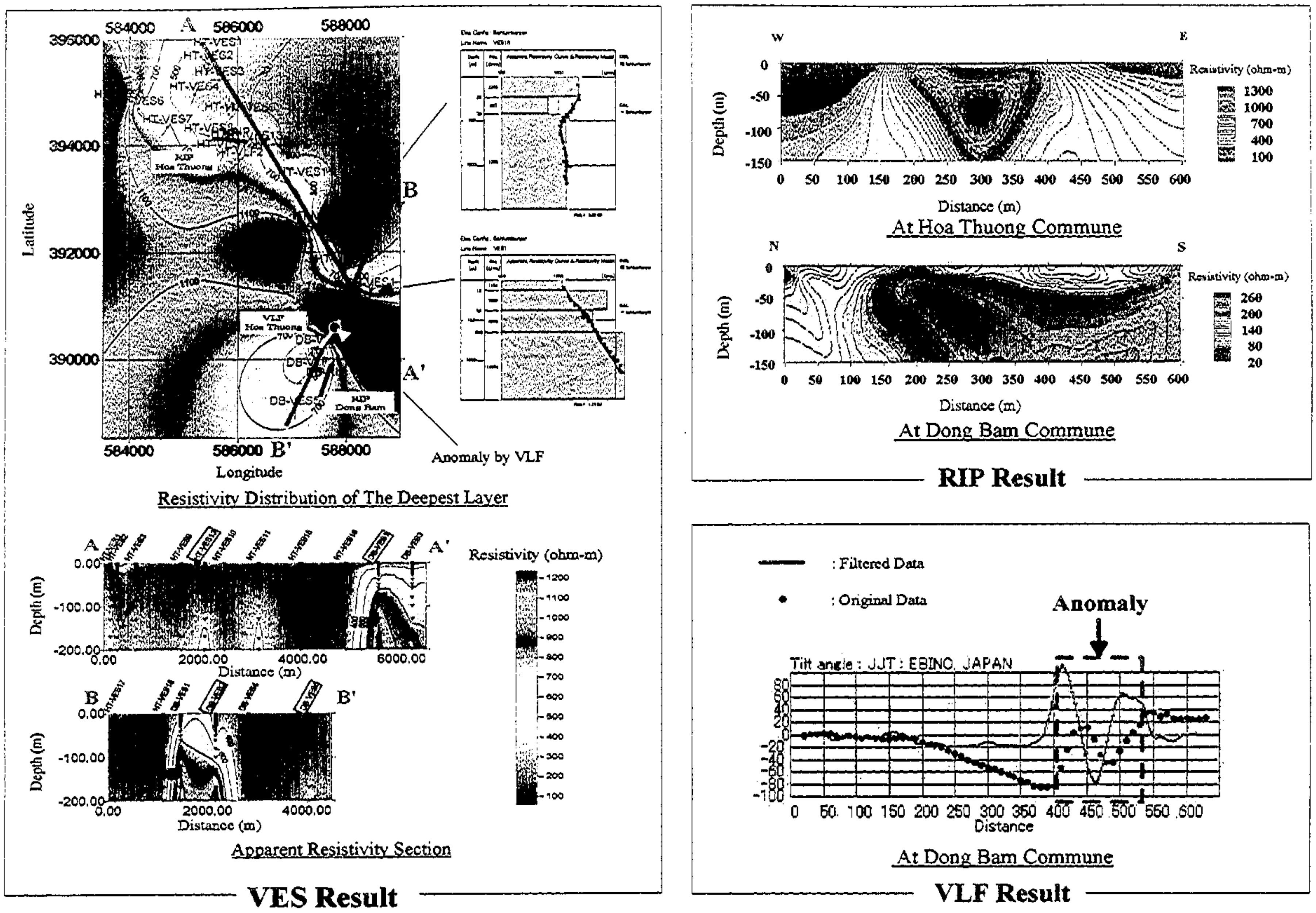


Figure 4.2.13 The Result of Geophysical Survey at Dong Bam and Hoa Thuong Commune in Thai Nguyen Province.

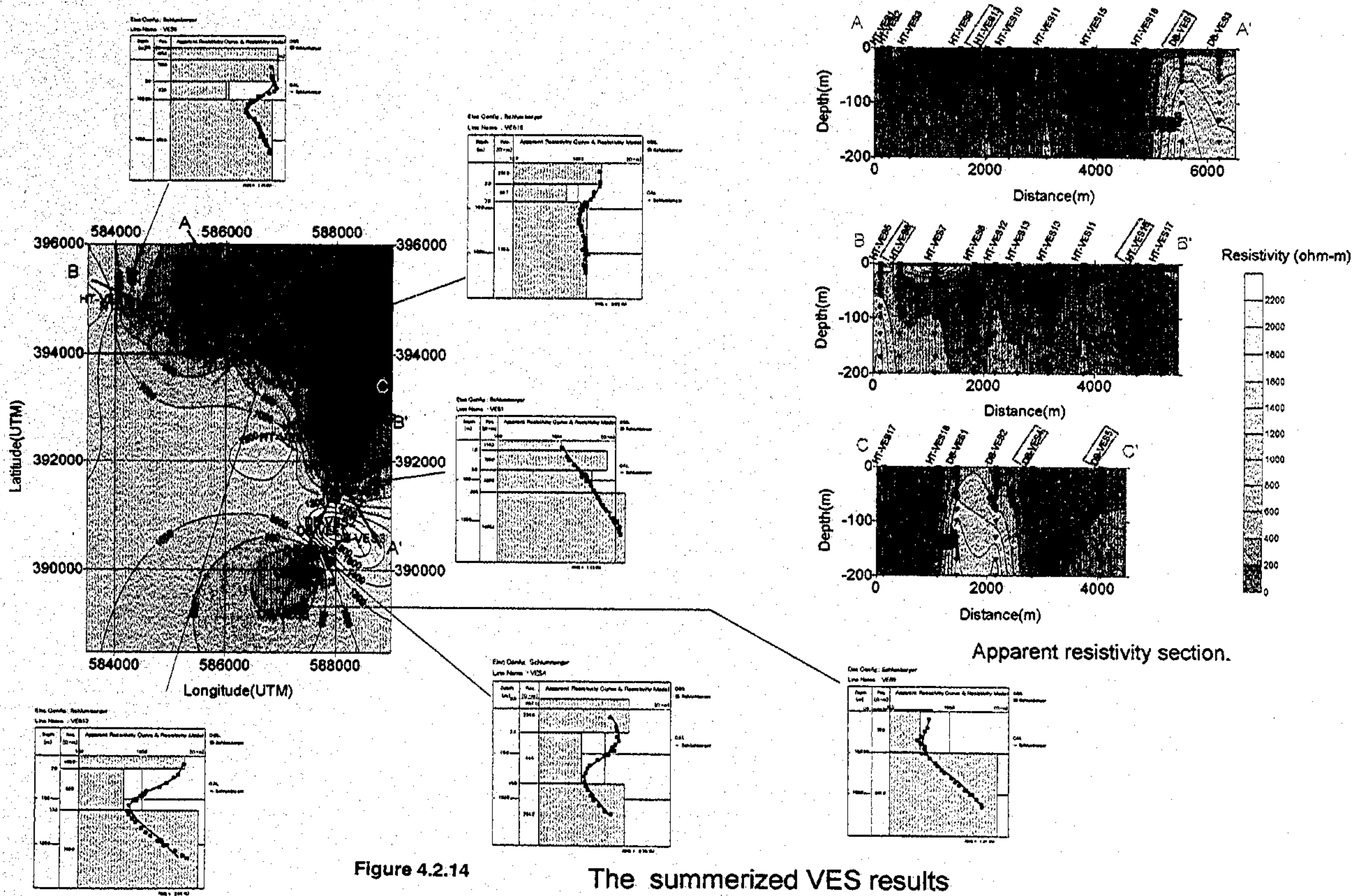


Figure 4.2.14 The summerized VES results in Dong Bam and Hoa Thuong commune ,Thai Nguyen province.

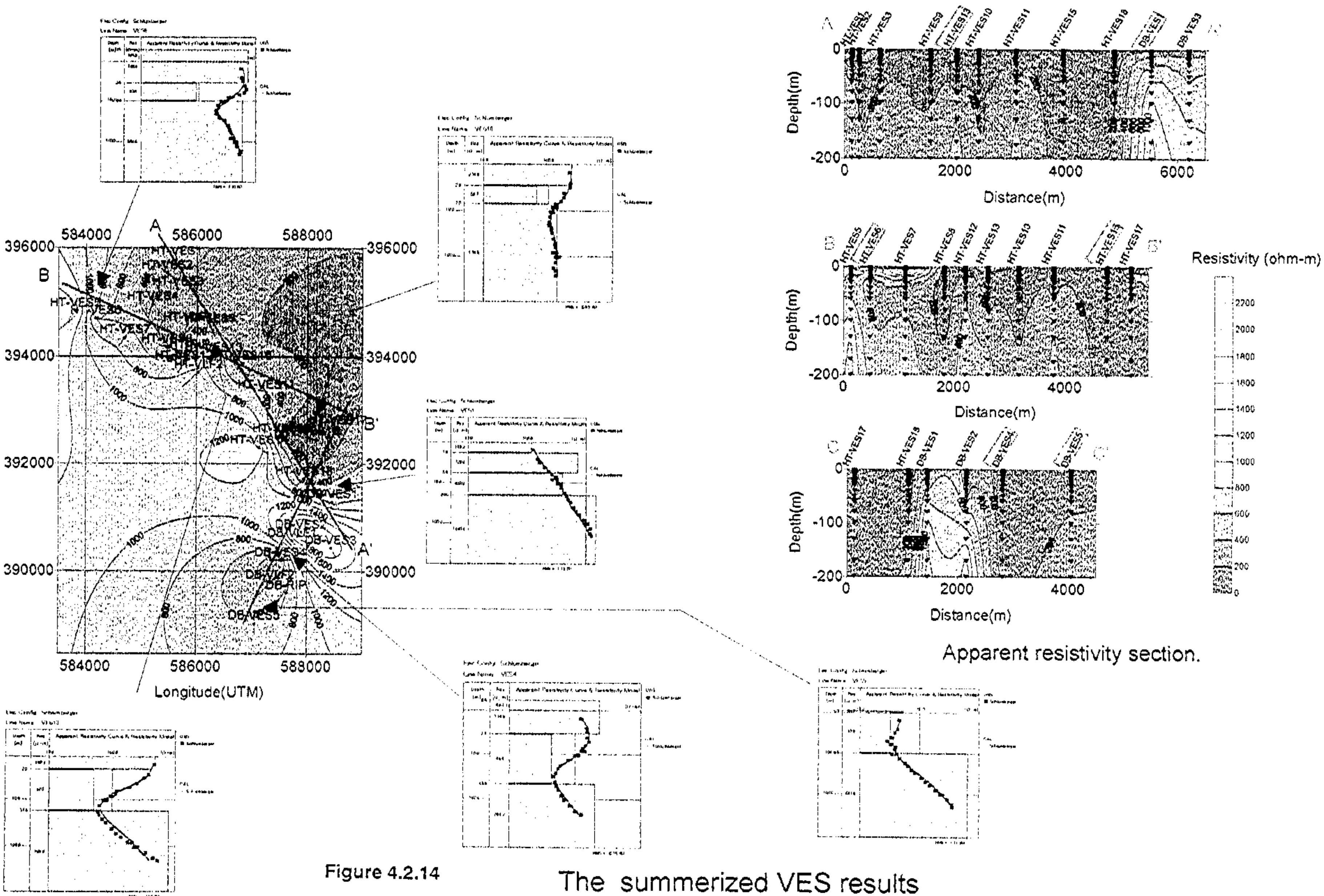
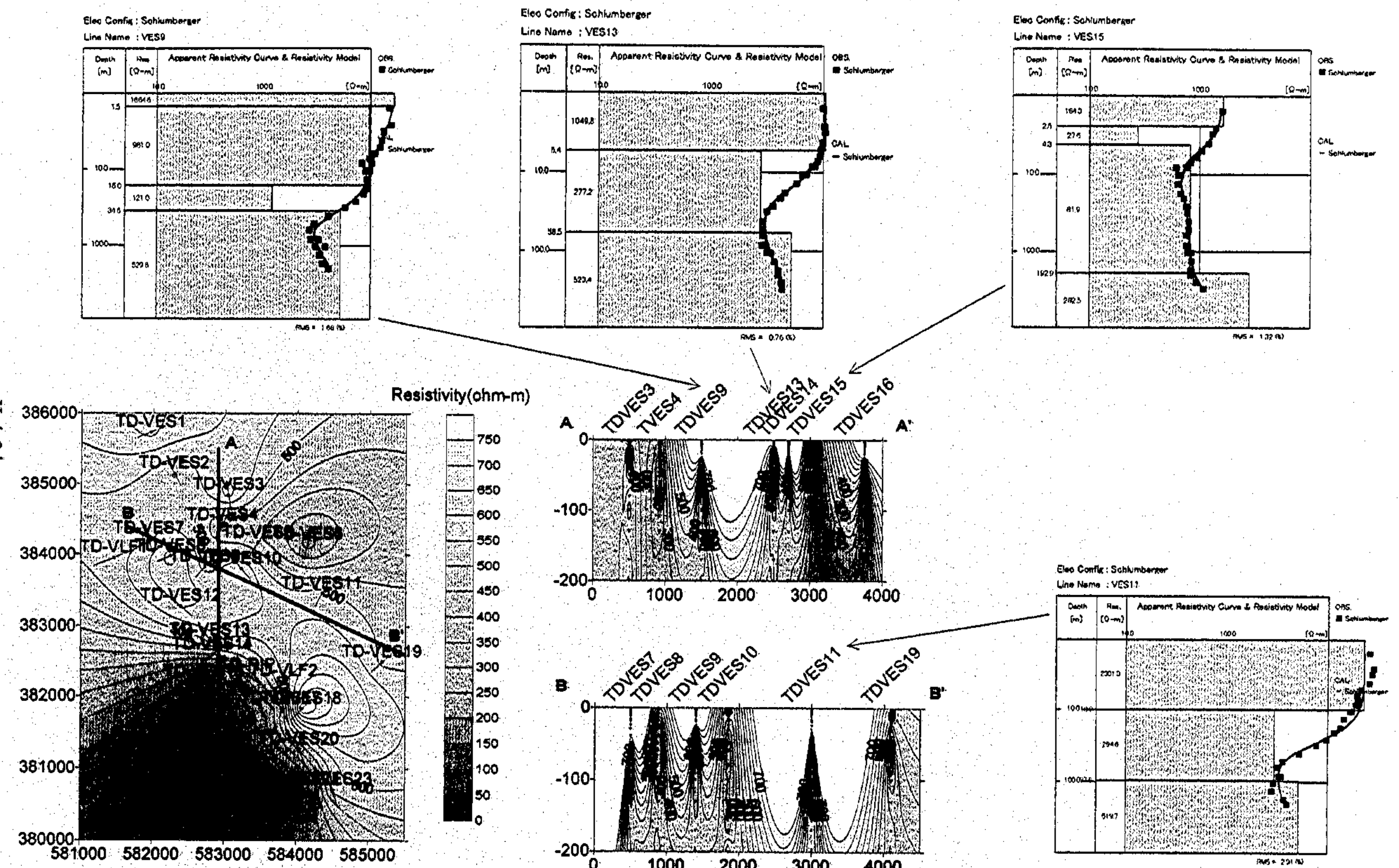


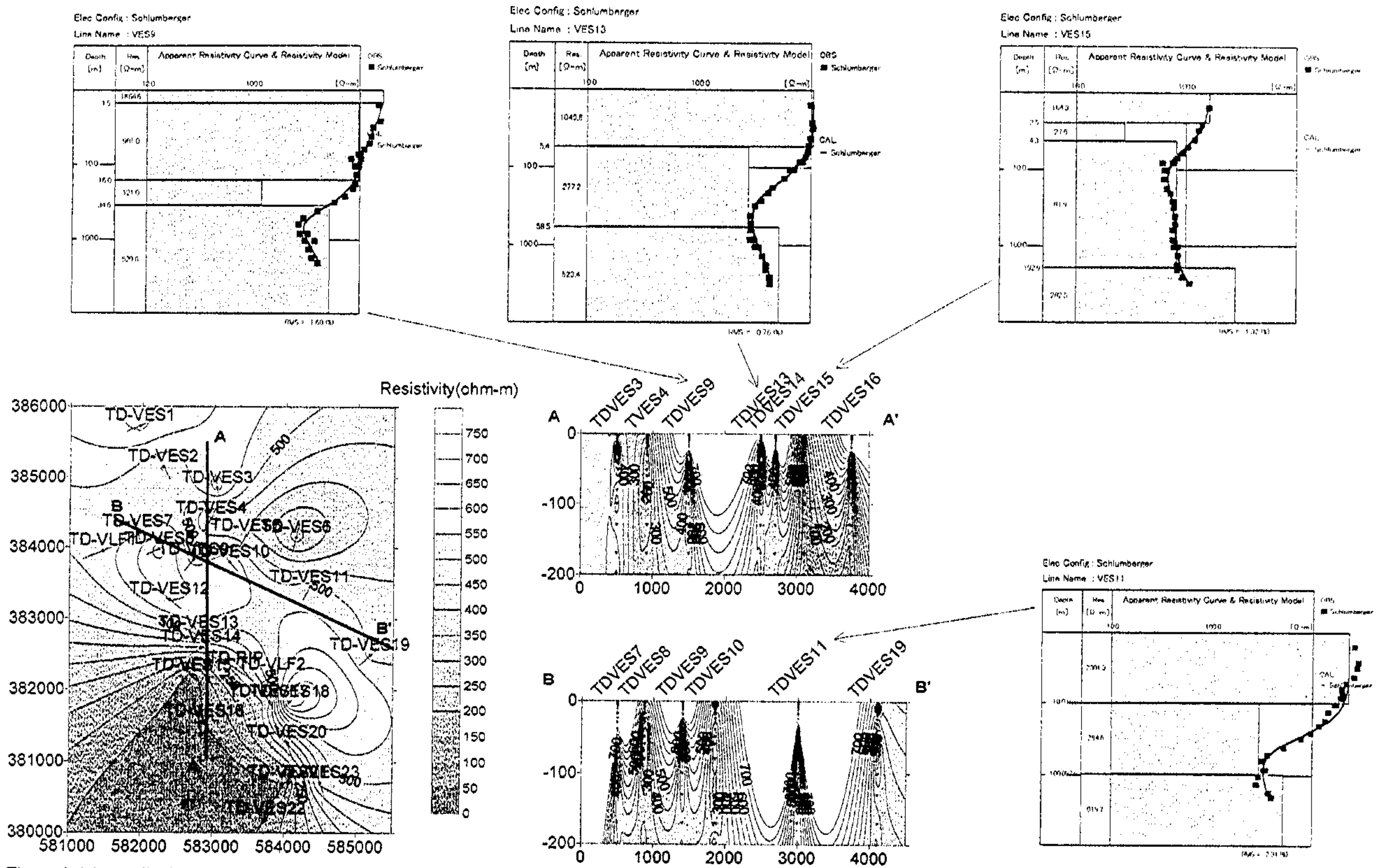
Figure 4.2.14 The summerized VES results in Dong Bam and Hoa Thuong commune ,Thai Nguyen province.



The resistivity dstribution of the deepest layer for the VES results

Apparent resistivity section for the VES measurements

Figure 4.2.15 **The summerized VES measurements in Thi h Duc commune, Thai Nguye province.**



The resistivity dstribution of the deepest layer for the VES results

Apparent resistivity section for the VES measurements

Figure 4.2.15 **The summerized VES measurements in Thinh Duc commune, Thai Nguyen province.**