Supporting 3-E

Electromagnetic Sounding Report

(Related to Chapter 3.2.1)

Electromagnetic Sounding Report

Akira Saito

1. The objectives of this technical training

The objectives of the training are consisted of two parts; one is to promote full understanding of the geophysical methods to the DDA personnel. The other is to lead to the full operational capability of the geophysical equipments rented by JICA. JICA rented two sets of geophysical systems, SYSCAL-R2 and PROTEM. DDA personnel are familiar with the SYSCAL system since it has been used in Myanmar for several times for the ground water explorations. On the other hand, the PROTEM system is completely new to them, and the main target of the training is to emphasize the theory, application, field operation of the PROTEM system.

2. Term of the training and trainee and the itinerary.

From 21 Nov. 2002 to 23 Dec. 2002

Mr. U Soe Naing
Assistance HydroGeologist
DDA, Yangon

Mr. Cung Lian Bawi
Assistant Engineer
Mandalay Division, DDA

Mr. U Aye Kyaw
Geologist
DDA, Yangon

Up two personels participated all the courses, but Mr. U Aye Kyaw can not enroll to the full training due to his involvement to on going drilling. Mr. Ko Phone Theint Ko (Geologist) also helped the field operation in Nyaung-U area.

Itinerary

11/21	Move from Mandarey to Nyaung-U
11/22 – 11/23	Supply necessary parts such as cables, batteries, fuel, oil.
11/24	Sunday
11/25	Test measurements using PROTEM and SYSCAL at KANGYIKONE village. (KGK01)
11/26	Test measurements using PROTEM and SYSCAL at HTANAUGWIR (HNW01)
11/27 – 11/28	Lecture on Geophysical theory and application for the groundwater explorations
11/29	practice teaching on the interpretation of the data using personal computers.
11/30	visit SETSETYO village area for the preparation of the survey.
12/1	Sunday
12/2	PROTEM survey at the villages, SETSETYO, PLANKAN, KUTAW and KYEOPINTA east. (SSY, FLK, KT, KPT-E)

12/3	Training of data interpretations using obtained data.
12/4	PROTEM measurements between THANTSHINKAN village and KANGYIKONE village. (TSK01 – TSK05)
12/5	PROTEM measurements at KANGYIKONE and THEPYINTAW village. (TSK06 – TSK08, TPT01)
12/6	PROTEM measurements at, MYETKHATAW, YPL, MAGWTAW and TABBANKON villages. (MKD01, YPL, MGT, TBK)
12/7	Practice of interpretation (TEMIXXL software)
12/8	Sunday
12/9	visit CHAUK DDA office and villages for the preparation of the survey.
12/10	PROEM measurements at SANGAN, SANZU and NEYWETAW villages. (SANGAN, SANZU, NYT)
12/11	PROEM measurements at YELAR, SHARPIN and NYAUPINTAW.
12/12	PROTEM measurements in MYINGYANG township, at KOKE and SAKA villages. (KOKE01, SAKA01)
12/13 – 12/14	Interpretation of acquired data.
12/15	Sunday
12/16	move to PYAWBWE township, visit DDA office and visit villages for the preparation.
12/17	PROTEM measurements at PAUKAINGYO, THABOK and YEBYU villages. Bull carts were used for the transportation in this area. (PAY, THABOK, YEPHYU)
12/18	PROTEM measurements at YONBINGON, KYETTE and THABYEYO villages. Return to NYAUNG-U. (YBG, KYETTE, THABYEYO)
12/19 - 21	Data interpretations. Check equipments.
12/22	Move from NYAUNG-U to MANDALEY.
12/23	Check and clean equipments and packing at the DDA MANDALEY office.
12/24 – 25	Data interpretations.

Total of 33 stations were measured and the abbreviations of the station names are shown in the above parentheses.

3. Electrical and electromagnetic methods

The contents of the lectures to DDA personnel consisted of 3 parts, one was the basic theory of geophysical methods in general, the second part was the electrical and electromagnetic methods, and the principles of the Geonics PROTEM system was explained in detail, the third was the interpretation techniques using TEMIX-XL program rented from JICA. In this chapter, the text used to explain the first part of the lecture is shown.

There are many methods of electrical and electromagnetic surveying. Some make use of naturally-occurring fields within the earth while others require the introduction of artificial currents into the ground. DC resistivity methods use direct currents. AC currents are used in electromagnetic methods, which are based on the electromagnetic induction phenomenon, called Faraday's law. Figure 3.1 shows typical classification of the electrical methods.

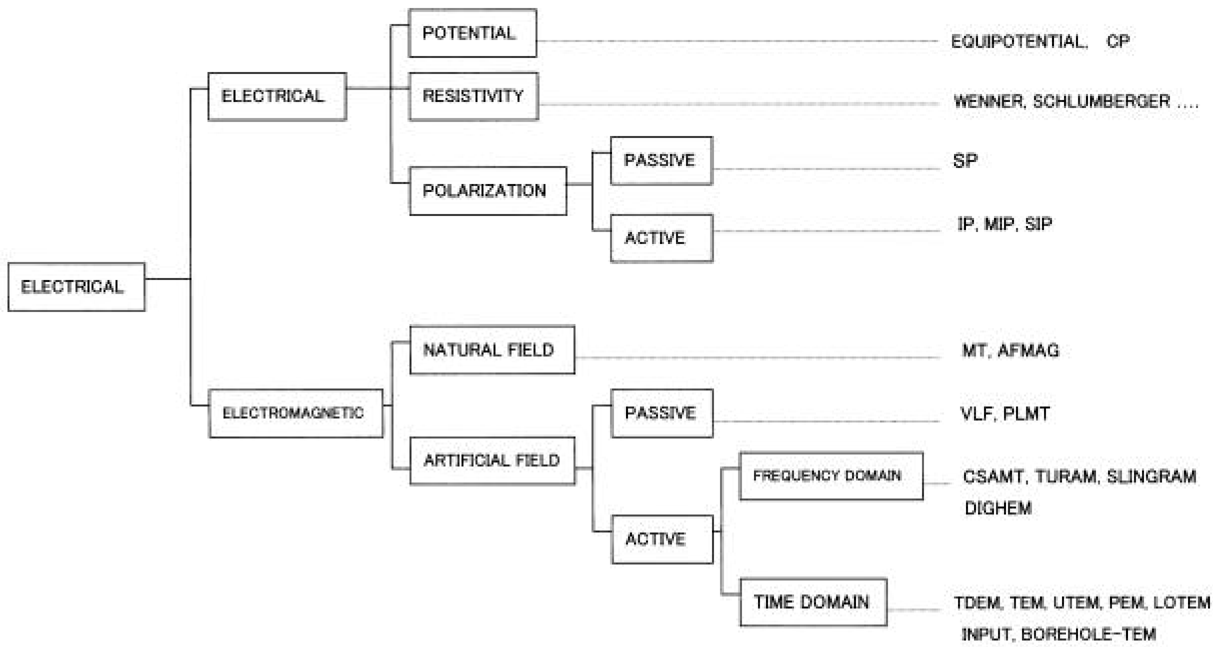


Fig. 3.1 Classification of Electrical methods

3.1 Resistivities of rocks and minerals

The resistivity of a material is defined as the resistance in ohms between the opposite faces of a unit cube of the material. For a conducting cylinder of resistance dR, 1ength dL and cross-sectional area dA (Fig. 8.1) thc resistivity r is given by

$$r = \frac{dR\,dA}{dL}$$

The SI unit of resistivity is the ohm-meter (ohm-m) and the reciprocal of resistivity is termed conductivity (units: Siemens (S) per meter).

Resistivity is one of the most variable of physical

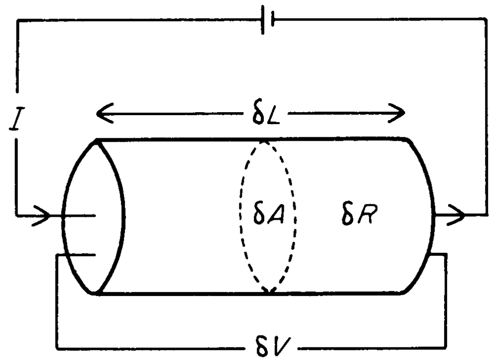


Fig. 3.2 Measurement of resistivity

properties. Certain minerals such as native metals and graphite conduct electricity via the passage of electrons. Most rock-forming minerals are, however, insulators, and electrical current is carried through a rock mainly by the passage of ions in pore waters. Thus most rocks conduct electricity by electrolytic rather than electronic processes. It fo11ows that porosity is the major contro1 of the resistivity of rocks, and that resistivity generally increases as porosity decreases. However, even crystalline rocks with negligible intergranular porosity are conductive along cracks and fissures. Figure 3.3 shows the range of resistivities expected for common rock types. It is apparent that there is considerable overlap between different rock types and, consequently, identification of a rock type is not possible solely on the basis of resistivity data. The effective resistivity can also be expressed in terms of the resistivity and volume of the pore water present according to an

Table 3.1 Resistivity range of rocks

Geologic age	Marine sand, shale, graywacke	Terrestrial sands, claystone, arkose	Volcanic rocks (basalt, rhyolite, tuffs)	Granite, gabbro, etc.	Limestone, dolomite, anhydrite, salt
Quaternary, Tertiary	1–10	15–50	10–200	500–2000	50–5000
Mesozoic	5–20	25–100	20–500	500–2000	100–10,000
Carboniferous	10–40	50–300	50–1000	1000–5000	200–100,000
Pre-Carboniferous Paleozoic	40–200	100–500	100–2000	1000–5000	10,000–100,000
Precambrian	100–2000	300–5000	200–5000	5000–20,000	10,000–100,000

Source: G. R. Keller, in "Handbook of Physical Constants," rev. ed., *Geol. Soc. Am. Mem.* 97, 1966.

empirical formula given by Archie(1942)

$$\frac{r}{r_w} = a f^{-m}$$

where f is the porosity, a and m are empirical constant, r_w is the resistivity of pore water.

3.2 Direct current resistivity method

The resistivity method is used in the study of horizontal and vertical discontinuities in the electrical properties of the ground, and also in the detection of three-dimensional bodies of anomalous electrical conductivity. It is routinely used in hydrogeological investigations to investigate the shallow subsurface geology.

In the resistivity method, artificially-generated electric currents are introduced into the ground and the resulting potential differences are measured at the surface. By knowing that current flowing through the ground and the resulting potential differences of voltage between two potential electrodes, it is possible to compute the resistivity of the earth materials. The four electrodes used are usually designated as follows,

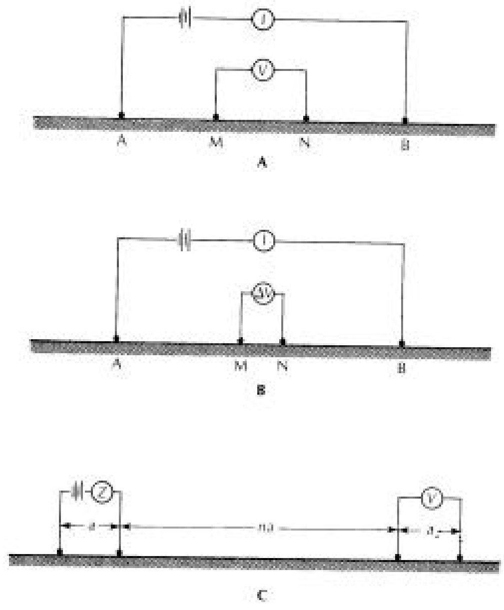


Fig. 3.3 Electrode configurations

A: the positive current electrode
B: the negative current electrode
M,N : the potential electrodes

Then apparent resistivity can be calculated by

$$r_a = \frac{2p}{\frac{1}{\overline{AM}} - \frac{1}{\overline{BM}} - \frac{1}{\overline{AN}} + \frac{1}{\overline{BN}}} \frac{\Delta V}{I}$$

There are several electrode configurations in common usage. Figure 3.3 shows Wenner (A), Schlumberger (B) and dipole-dipole (C) arrays. The Wenner array consists of the four electrodes spaced equal distances apart in a straight line: $\overline{AM} = \overline{MN} = \overline{NB} = a$, and the apparent resistivity is obtained by

$$r_a = 2p\, a \frac{\Delta V}{I}$$

A second configuration is the Schlumberger array. It is a linear array, with potential electrodes placed close together. Typically, $\overline{AB}$ is set equal to or greater than five times the value of $\overline{MN}$. The apparent resistivity is given by

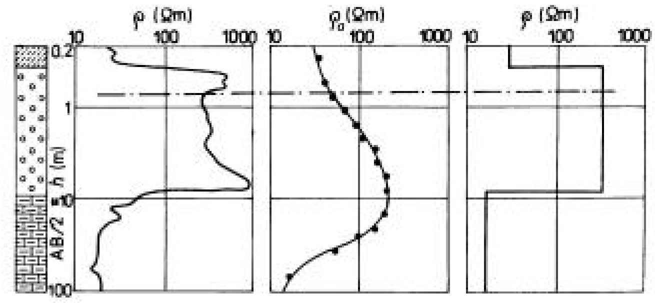
$$r_a = p \frac{\left(\frac{\overline{AB}}{2}\right)^2 - \left(\frac{\overline{MN}}{2}\right)^2}{\overline{MN}} \frac{\Delta V}{I}$$

The dipole-dipole array is particularly convenient for making electrical sounding and IP measurements. The apparent resistivity for the dipole-dipole array is given by

$$r_a = n(n+1)(n+2)\, a \frac{\Delta V}{I}$$

Resistivity surveys are made in two fashions. An electrical sounding will reveal the variations of apparent resistivity with depth, while horizontal profiling is used to determine lateral variations in resistivity. When the electrode spacing is expanded in making an electrical sounding, the distance between the potential electrodes and current electrodes increases. The current will be travel progressively deeper through the ground and will measure apparent resistivity to greater depths.

Figure 3.4 shows an example of resistivity logging (a), Schlumberger electrical sounding (b) and result of the sounding interpretation. The top layer is loam, the second layer is sand and sandy gravel, the third is the marlstone.



(a)

(b) (c)

Fig. 3.4 Example of DC resistivity method

3.3 Electromagnetic methods

Electromagnetic (EM) methods make use of response of the ground to the propagation of electromagnetic fields, which are composed of an alternating electric intensity and magnetic force fields. Primary electromagnetic fields may be generated by passing alternating current through a small coil made up of many turns of wire or through a large loop of wire. The response of the ground is the resultant fields may be detected by the alternating currents that they induce to flow in a receiver coil by the process of electromagnetic induction.

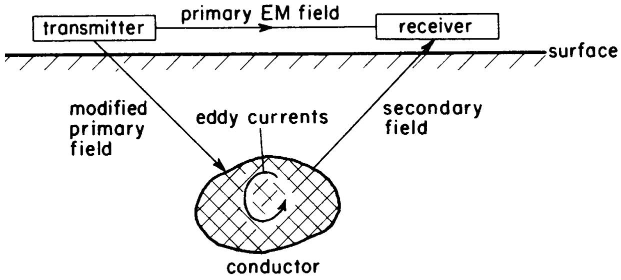


Fig. 3.5 Principle of electromagnetic method

The primary electromagnetic field travels from the transmitter coil to the receiver coil via paths both above and below the surface. In the presence of a conducting body the magnetic component of the magnetic field penetrating the ground induces alternating currents, or eddy currents, to flow in the conductor (Figure 3.5). The eddy currents generate their own secondary electromagnetic field which travels to the receiver. The receiver then responds to the resultant of the arriving primary and secondary fields so that the response differs in both phase and amplitude from the response to the primary field alone.

There is no need for physical contact of either transmitter or receiver with the ground. Surface electromagnetic surveys can be proceed much more rapidly than electrical surveys which require ground contact. Both transmitter and receiver can be mounted in aircraft or towed behind them. Airborne EM methods are widely used in prospecting for a remote area.

The depth of penetration of an electromagnetic field depends on its frequency and the electrical conductivity of the medium through which it is propagating. Electromagnetic fields are attenuated during their passage through the ground, their amplitude decreasing exponentially with depth. The depth of penetration d can be defined as the depth at which the amplitude of the field A is decreased by a factor of 1/e (about 1/3) compared with its surface amplitude A_0

$$A = A_0 \, e^{-1}$$

In this case the depth d is expressed as

$$d = 503.8\sqrt{1/s \;\; f}$$

where d is called skin depth , and s is the conductivity of the ground, and f is the frequency of the electromagnetic field in Hz.

There are several different electromagnetic methods used for hydrogeological purposes. In these days, VLF method, slingram method and time domain EM methods are commonly used for the groundwater exploration.

3.3.1 VLF method

Electrical properties of the ground affect the behavior of radio wave. Radio waves at VLF frequencies (15-25kHz) can be used to prospect for electrically conductive faults and fractures. Instruments basically measure either magnetic field tilt angle or the vertical or horizontal magnetic field strengths to detect the presence of localized electrically conductive targets. Some are magnetotelluric type instruments which measure horizontal magnetic and electric field phase angle between them. Typical equipment is shown in Figure 3.6, which is Geonics EM 16R system and can be used for tilt angle (VLF-EM) and magnetotelluric (VLF-MT) measurements.

Communication at VLF frequencies is used with priority for most of the world's major navies, the reasons being that at these frequencies (1) global communications are possible, and (2) the effective penetration depth into sea water is large enough to permit submarines to receive VLF signals while submerged. Figure 3.7 shows the locations of main VLF stations. In Japan, Yosami station (NDT) has finished the operation and now Ebino station (JJI, 22.2kHz, 500kw) is now operating. The selection of VLF station to use the survey is very important. Figure 3.9 shows an example of the use of VLF method, where VLF and DC-resistivity methods showed good anomaly. Drilling of conductor B revealed a productive aquifer.

EM16 / EM16R / TX27

The EM16 is the most widely used EM instrument of all time. It measures the local tilt and ellipticity of VLF broadcasts, and resolves these values into inphase and quadrature components of VLF response. The EM16 has discovered several base- and precious-metal orebodies, and many water-bearing faults.

The EM16R attaches to the EM16 and, using a pair of electrodes, measures the apparent resistivity of the earth. The combined EM16/16R instrument can detect a second earth-layer if the layer occurs within the VLF skin-depth. In addition, the EM16/16R can map resistive alteration for gold exploration.

The TX27 is a portable VLF transmitter supplying a VLF field for surveying with the EM16/16R, if remote broadcasts are weak, intermittent or poorly coupled with the target. For EM16 surveys, the TX27 antenna consists of a long (1 km) grounded wire.

Fig. 3.6 Example of a VLF instrument

	Frequency (kHz)	Power (kW)
Bordeaux, France (FUO)	15.1	500
Rugby, Great Britain (GBR)	16.0	750
Hegeland, Norway (JXZ)	16.4	350
Gorki, USSR (ROR)	17.0	315
Moscow, USSR (UMS)	17.1	1000
Yosamai, Japan (NDT)	17.4	500
Oxford, Great Britain (GBZ)	19.6	550
Annapolis, USA (NSS)	21.4	400
Northwest Cape, Australia (NWC)	22.3	1000
Laulualei, Hawaii, USA (NPM)	23.4	600
Buenos Aires, Argentina (LPZ)	23.6	
Cutler, Maine, USA (NAA)	24.0	1000
Seattle, Washington, USA (NLK)	24.8	125
Aguada, Puerto Rico (NAU)	28.5	100

Fig. 3.7 VLF stations

3.3.2 Slingram Methods

The slingram method was originally developed and used in Sweden in the min 1930s and was first used extensively in North America in the 1950s.The Swedish term ‘SLINGRAM’ is sometimes translated into English as loop-frame. Slingram methods use small aircore or ferrite core transmitter coil and receiver coil of various orientations.

The secondary EM field measured in a mobile transmitter-receiver survey is generally a complex function of the coil spacing s, the operating frequency f and the conductivity of the subsurface s. However, it can be shown that if the product of s and the skin depth d, known as the induction number, is much less than unity, the following relationship can be obtained

$$\frac{H_s}{H_p} = \frac{iwm_0 s\ s^2}{4}$$

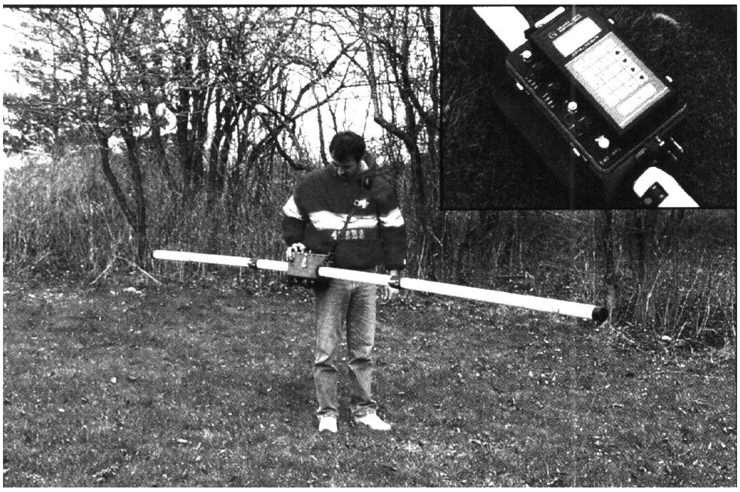


Fig. 3.10 EM31 Slingram system

where H_S and H_p are the amplitude of the secondary magnetic fields respectively, $w = 2p\ f$ and m_0 is the magnetic permeability of vacuum and i is the complex number. Thus by measuring the ratio H_s / H_p, we can obtain ground apparent conductivity s_a from the next equation

$$s_a = \frac{4}{w\, m_0\, s^2} \frac{H_s}{H_p}$$

The relationship allows the construction of electromagnetic instruments which provide a direct reading of ground conductivity down to a predetermined depth. In one application the transmitter and receiver are horizontal dipoles mounted on a rigid boom. Figure 3.10 shows an example EM31, which uses 3.66. boom and about 10 kHz frequency. The instrument provides a rapid

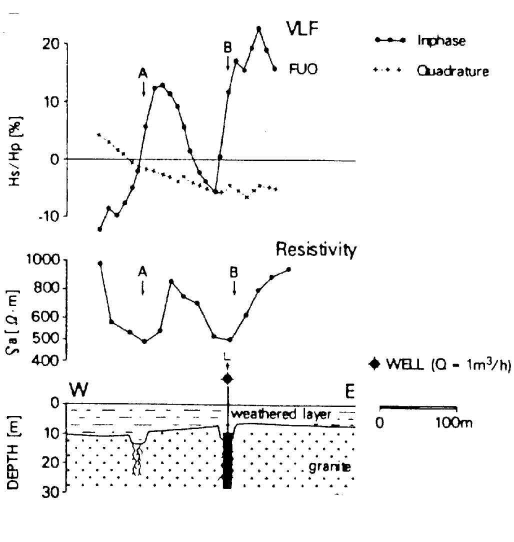


Fig. 3.9 Example of VLF method

means of performing constant separation traversing to a depth suitable for hydrogeology , engineering and archaeological investigations. Where a greater depth of penetration is required, an instrumentis used in which the transmitter and receiver, which usually take the form of vertical coplanar coils, are separate, so that their spacing is variable. An example of such instruments is shown in Figure

Fig. 3.11 EM34 Slingram system

3.11, the frequency range of which is from 400Hz to 6.4Khz and the saparation from 10m to 40m. Figure 3.12 shows schematic responses of slingram systems. Depth of investigation is greater if we use horizontal loops (vertical dipole) then vertical loop. Figure 3.13 shows the difference of the responses of EM 31 and EM 34 for gravel under the overburden.

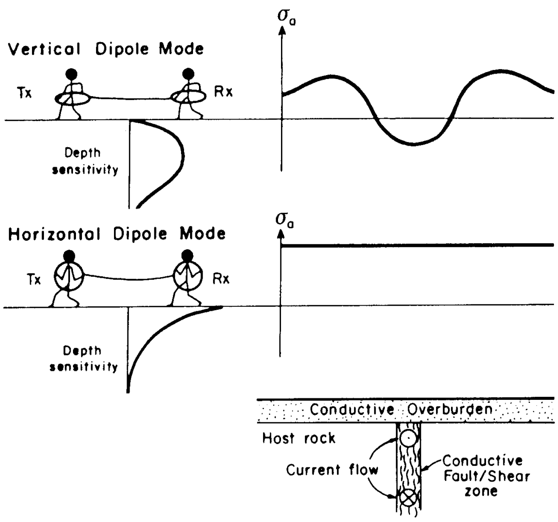


Fig. 3.12 Response of conducting dyke

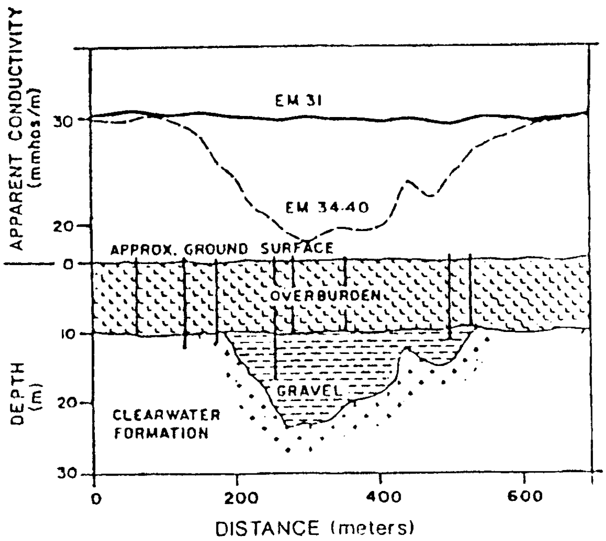


Fig. 3.13 Response of underlying gravel

3.3.3 Time-domain electromagnetic methods

A significant problem with many electromagnetic methods is that a small secondary field must be measured in the presence of a much larger primary field, with a consequent decrease in accuracy. This problem is overcome in time-domain electromagnetic method (TDEM), or also called transient electromagnetic method (TEM).A series of pulses are applied to the transmitter loop, and the secondary field induced by the primary is only measured during the interval when the primary is absent. The eddy currents induced in a subsurface confined conductor tend to diffuse inwards when the inducing field is removed and gradually dissipate by resistive heat loss (Joule loss). Within highly conductive bodies, however, eddy currents circulate around the boundary of the body and decay more slowly. The decaying magnetic field at the surface, which is generated during the period that the primary magnetic field is off, is measured relatively easily to detect subsurface conductive bodies or measure the conductivity of the earth itself.

Two configurations are useful in groundwater studies. The first is the Slingram mode in which the small transmitter and receiver are moved together down the survey line as for the frequency domain system. The Slingram configuration is particularly useful when exploring for steeply dipping conductive target as well as localized thickening of the overburden. The separation between transmitter coil and receiver coil is usually called offset, and is optimized for the depth and type of the target to be explored. In the time domain, such a configuration has several important differences over the frequency-domain system. Constrains on maintaining the exact intercoil offset and coil alignment are greatly reduced since the measurement is made in the transmitter off-time. Also, since there are fewer problems in determining the zero-level of the received signals, accurate sounding can be possible. Recently developed TDEM systems have very large bandwidths. Measurement of the anomalous transient magnetic field can commence at times of a few microseconds after transmitter turn-off.

The second configuration in which TDEM systems are commonly used is the central loop sounding mode in which a square single-turn transmitting loop of edge dimension typically 20 to 150 m for groundwater studies is laid out for each sounding with the receiving coil located at the loop center. When the transmitter shuts off, rapidly terminating the primary magnetic field, eddy currents are instantly generated near the transmitting wire so as to maintain the magnetic field in the earth at the value that existed just before cut-off (Figure 3.14). These horizontal eddy currents diffuse to greater depths and expand in radius with the passage of time. Measurement of the decaying magnetic field at the loop center as a function of time is equivalent to measurement of resistivity as a function of time. Microcomputer programs are commonly used which invert the decay curve data into geoelectric sections.

The TDEM technique has several advantage s and some disadvantages compared with conventional frequency domain electromagnetic and DC resistivity methods. TDEM is a much faster procedure to carry out than DC resistivity methods because once the transmitting loop has been laid down the actual sounding takes only a few minutes. To increase production, several transmission can be laid down in advance. Another feature is that, unlike conventional dc resistivity soundings where the total array length is several times the depth of investigation, in the case of TDEM the depth of exploration is larger than the loop size, with the result that lateral resolution is excellent.

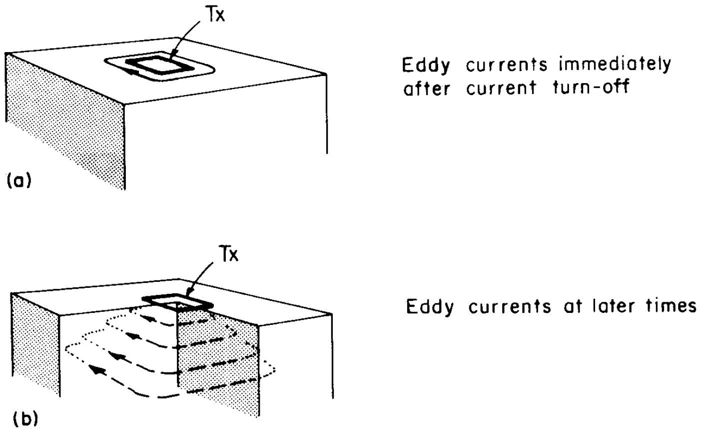


Fig. 3.14 Diffusion of eddy currents

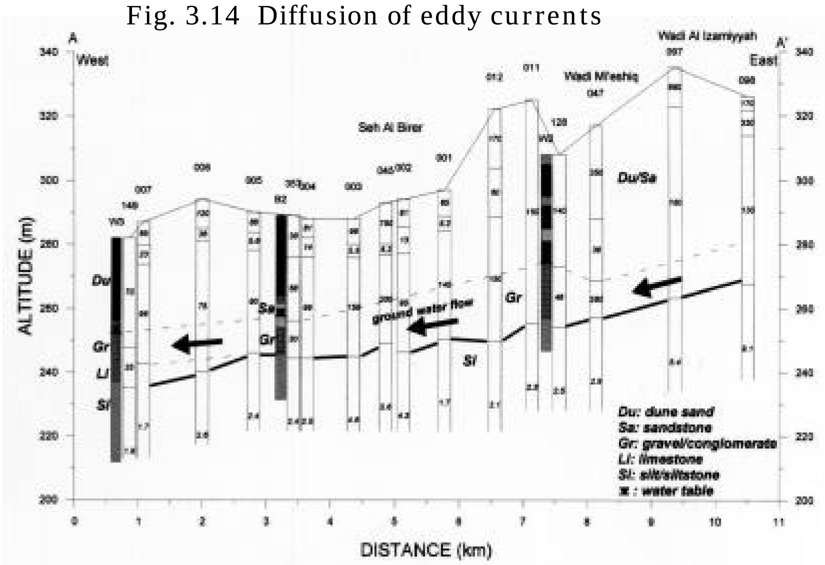


Fig.3.15 Resistivity section from TDEM

Furthermore , since TDEM does not use electrode, there is no static shift. Resolution of several types of equivalence for conductive layers is also better than conventional dc resistivity methods. The major disadvantages of the TDEM technique are that since the decaying transient covers an enormous dynamic range of about 4 decades the equipment is relatively complicated and thus expensive.

Figure 3.15 shows an example of TDEM survey, the purpose of which was to map the depth to the aquiclude for the design of underground dam.

4. Results of the measurements

Although the main purpose of this technical training is to lead the DDA personels to have the capability of measurements and interpretation techniques, as many stations were selected as possible to show the importance of the reasonable quick operation. The resistivity measurements up to 300 to 500m can be archived using the outer electrode separation (AB/2) of 500 to 1000m, in case of Schlumberger sounding using SYSCAL system. The requied time of this measurements varies significantly according to the surface conditions such as terrain vegetations and road conditions. The average time in the central dry zone is 4 to 6 hours with the separation of 500 m. The depth of investigations using the Schlumberger sounding with the maximum AB/2 separation of 500m would be 300m or less depending on the resistivity values of the formations. To get deeper information is more difficult with the decrease of the resistivity, and almost all the area measured in this training the resistivities were extremely low. That means that to get the information of over 300 m, electrode spacing of 1000m would be required and field operation takes six to 10 hours to complete.

4.1 Comparison of SYSCAL and PROTEM results

At the KANGYIKON area, resistivity structures were measures using both SYSCAL and PROTEM systems. The Schlumberger measurement took about 4 hours to complete for the separation (AB/2) of 500m. For the PROTEM survey, it took about one hour to

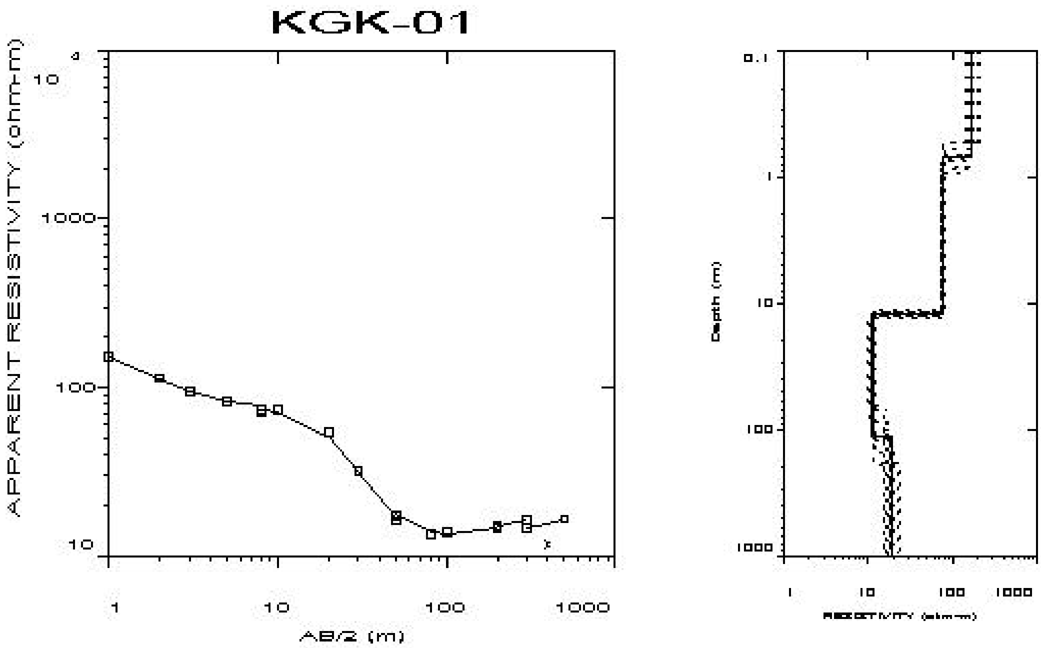


Fig.4.1 Result of Schlumberger sounding (KANGYUKON)

layout 100*100 m transmitter loop and measure three frequencies (H, M and L). Fig4.1 and 4.2 shows the results of the Schlumberger and PROTEM soundings (layered inversion) respectively.

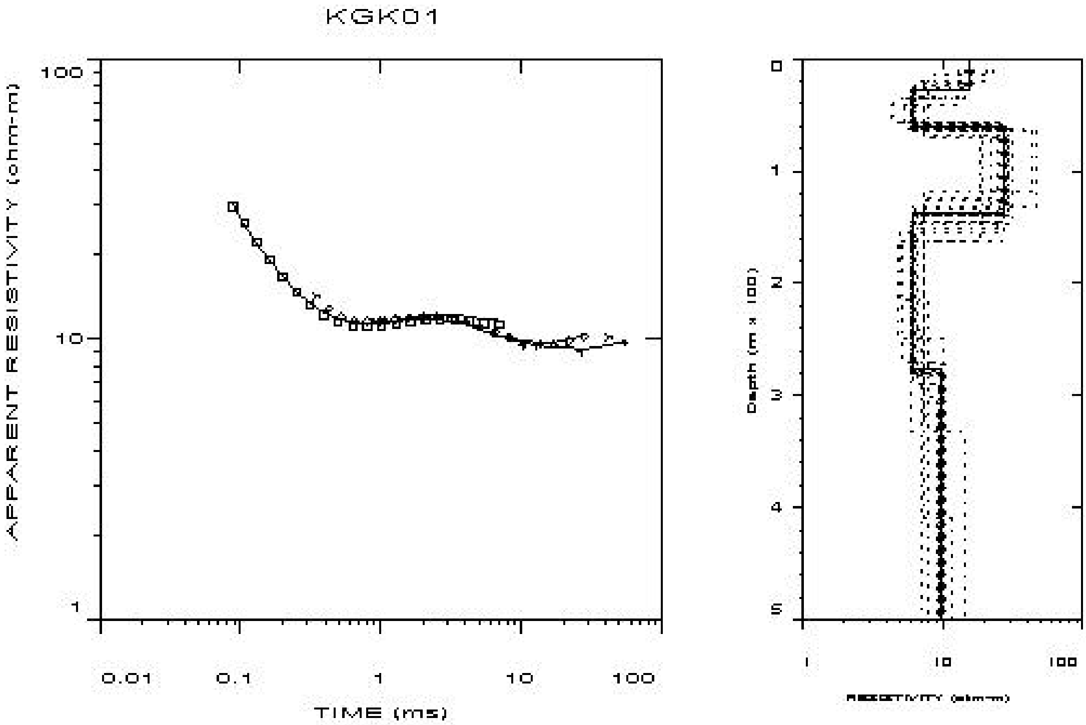


Fig 4.2 Result of PROTEM measurement '(KANGYIKON)

The results of the two methods resemble but few differences:

① DC resistivity result shows higher surface resistivities of about 100 ohm-m, on the other hand, EM resistivity shows the surface resistivities of about 10 ohm-m. The minimum electrode spacing (AB/2) of the Schlumberger method was set to 1m and better resolution can be achieved compared to the PROTEM 57 system, which is designed to relatively deep sounding.

② PROTEM measurement detected conductive (about 7 ohm-m) layer between 30 to 60 m.

③ Resistivities of the deepest layers for Schlumberger sounding and PROTEM EM sounding are 20 ohm-m and 10 ohm-m respectively. Very often PROTEM resistivity shows lower values compare to the DC soundings because of the horizontal induction currents caused by the sudden interruption of the transmitter loop.

4.2 Results of KANGYIKONE area, NYAUNG-U township

At KANGYUKON village, no water was obtained from the well depth between 100 to 200m. Since good water is obtained from the well at the THANSHINKAN village, about 4 km west of KANGYIKON village, total eight measurements were performed from the THANSHINKAN to KANGYIKON villages to check the difference of the geological structures. Figure 4.3 shows the position of the measured stations TSK01(near the successful well) to TSK08 (east 80m of KANGYIKON well), THEPYINTAW well (abandoned due to saline).

The smooth inversion results of this area are shown in Fig. 4.4. KANGYIKON well is located between KGK01 and TSK08 stations. Deep high resistivity layers were detected from 250 to 400m depth, and there are some possibility we can get water from this zone. Both THANSHINKAN and HTANAUGWIR (HNW01) wells, water can be obtained from the depth of 100m, that means aquifers are resistive layers above the very conductive layers which are situated between 100 to 250 m varying from the stations. At present, it is very hard to decide whether we can get water of good quality from there lower resistive layers.

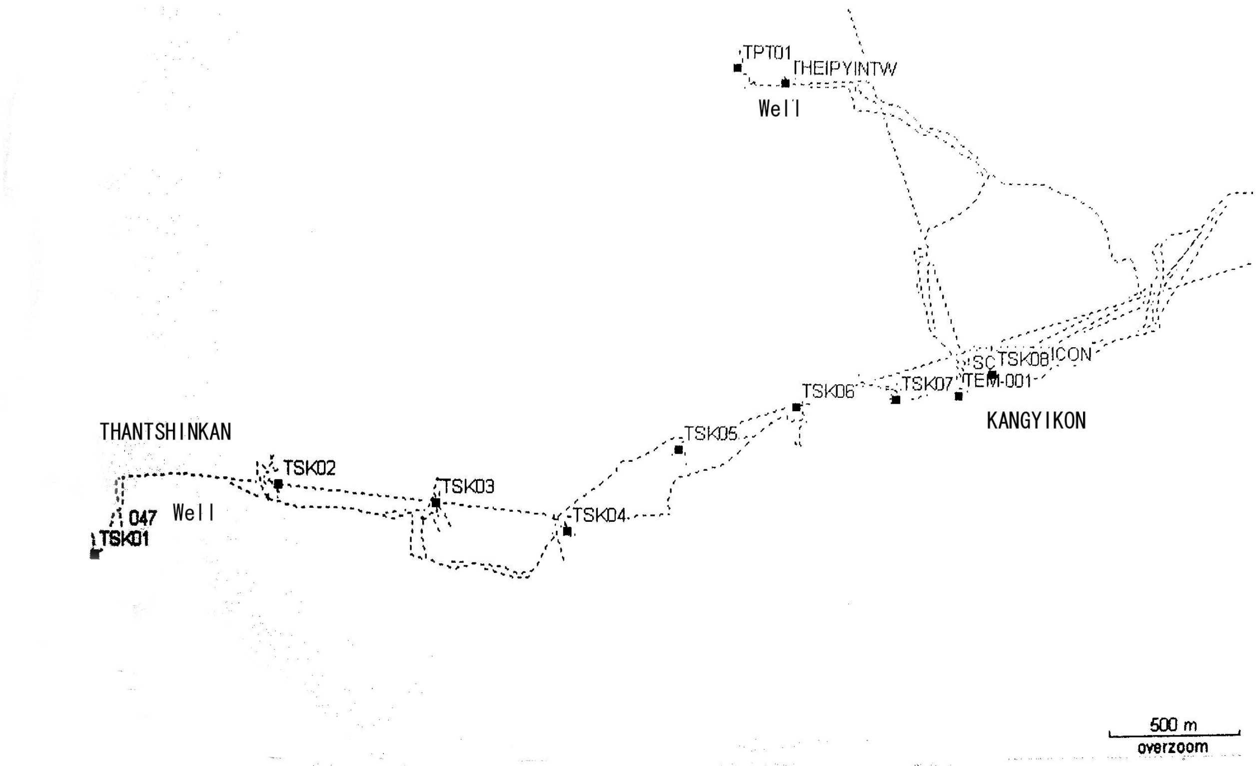


Fig 4.3 Stations between THANTSHINKAN and KANGYIKON

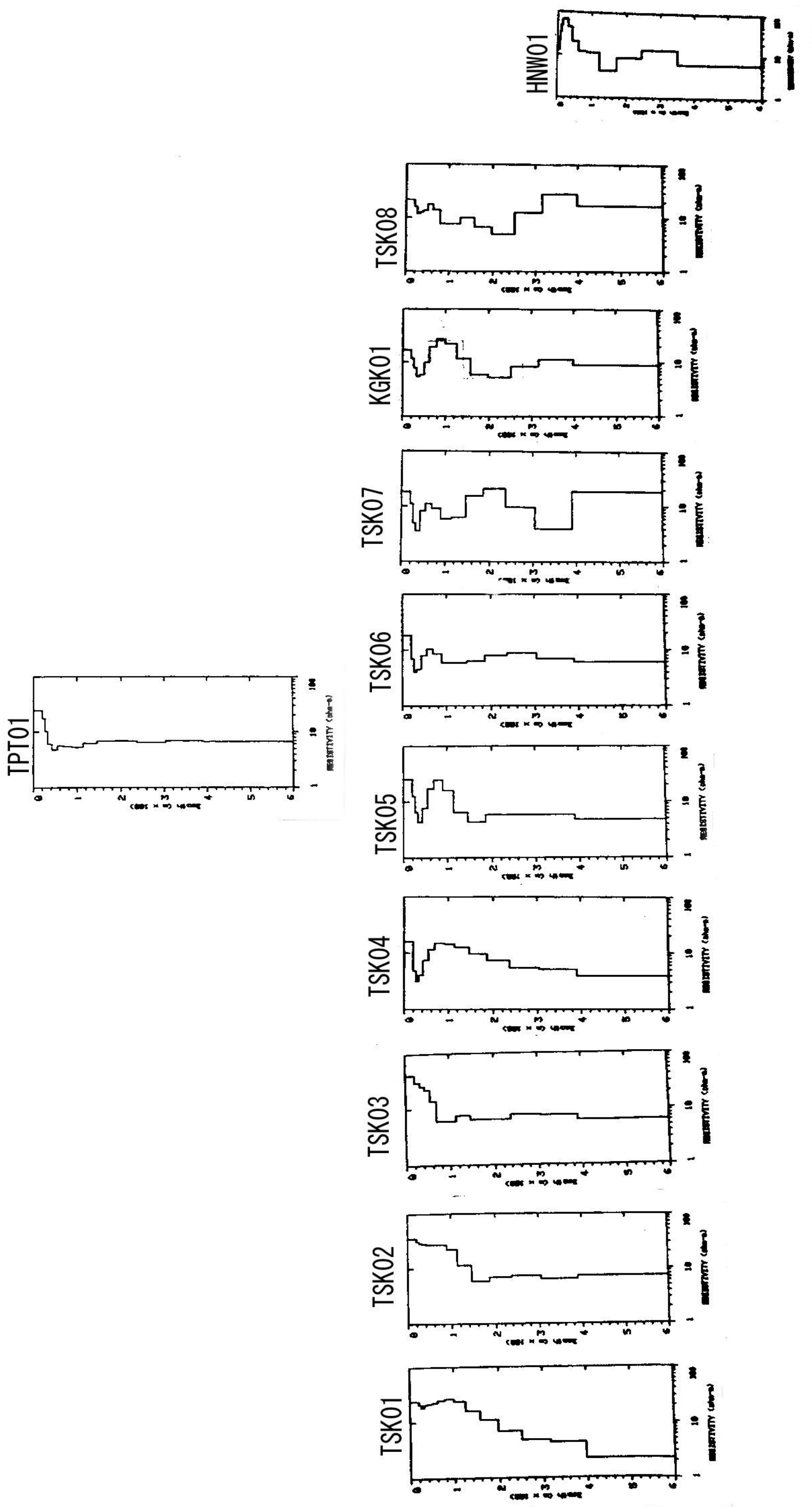
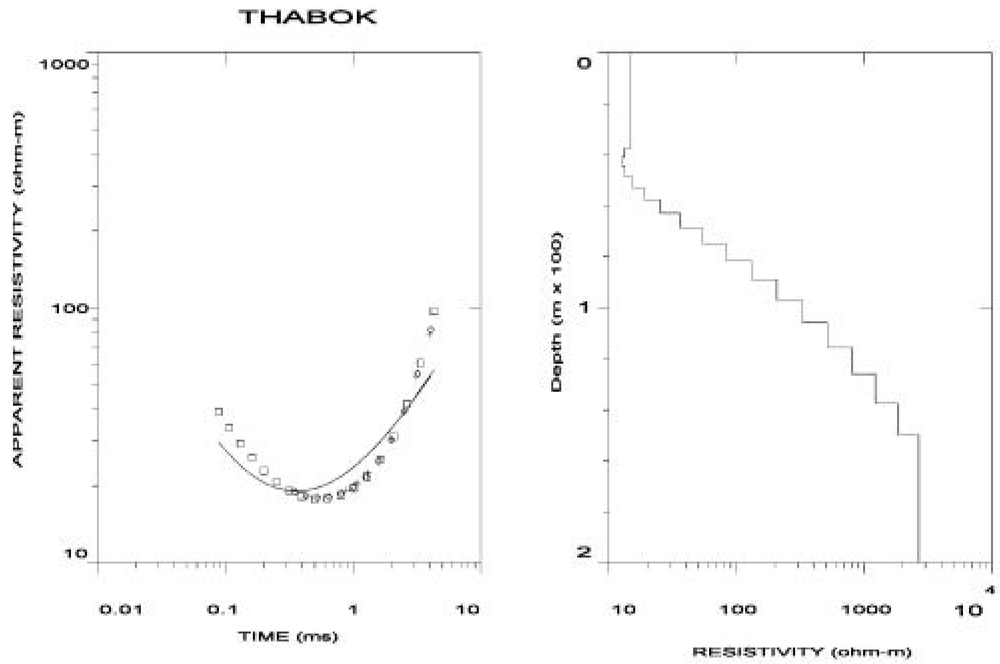


Fig. 4.4 Smooth inversion results

4.3 Results of PYAWBWE Township

Fig 4.5 and 4.6 show the results of the THABOK and YEBYU villages, PYABWE township. Both shows very high resistivity basement, could be Granite or Schist. Smooth inversion could not fit to the measured data. The reason should be inclined surfaces of the resistive rocks. One dimensional inversion can not work well in such highly resistive two dimensional structures. 2D or 3D interpretations are required in



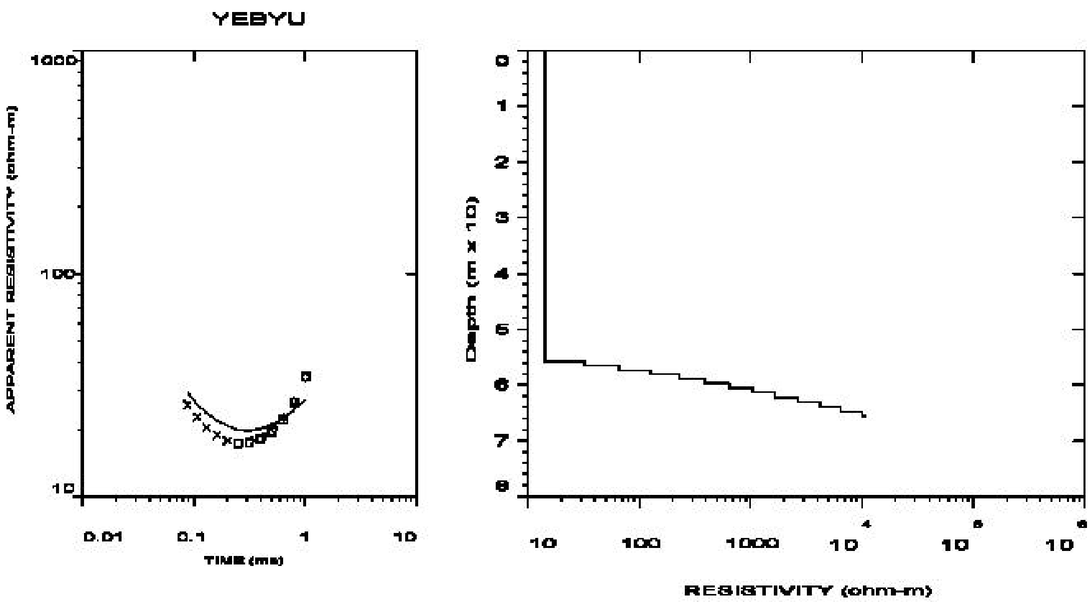


Fig 4.6 Smooth Inversion result of YEBYU village data

such area. And the water can be obtained inside the fractures of the resistive rocks. For this purpose, more high density on line measurements are necessary to detect the fractures. And rented EM-57 transmitter is not adequate for such resistive environments. EM-47 transmitter with high frequency coil will fit to the measurements of such area.

4.4 Summary of the training

Training was consisted of three parts, lectures (5 days), field operations (16 days) and interpretation (5 days). Also it took 5 days to obtain necessary parts such as cables, and consumable items like fuel, oil and batteries.

(1) DC RESISTIVITY Methods.

DDA Personnel has experiences using the SYSCAL-R2 system and interpretation. They can pursue measurements by themselves without any difficulty. But their understanding of the accuracy of the measurements was not enough to apply the methods to such low resistivity area as the central dry zone.

Curve matching techniques using standard curves were explained in this training since the access to the computer might be not always possible, and also this techniques helps the total understanding of the behavior of the measured apparent resistivity data.

The interpretation techniques using INTERPEX RESIS-PLUS program was also explained in detail. They have some experiences of the use of such software, but they have some difficulty using the computer in DOS Prompt mode. DOS commands are not used in WINDOWS environment any more, but due to the design of the Interpex programs, the use of several DOS commands are needed to start the RESIX-PLUS program.

(2) Electromagnetic methods using PROTEM

Time domain electromagnetic methods are relatively new techniques in the world, since the measurements are possible using advanced electronics and microcomputer techniques. These time domain techniques are now commonly used in USA, CANADA, RUSSIA, JAPAN, CHINA and many other countries. In Australia, this method is the main geophysical technique they can use due to the very conductive surface layers. The situation is similar in the Central Dry Zone. Overall resistivities in the central dry zone are very small. For example, in KOKE and SAKA stations, resistivities of less thaqn one ohm-m were obtained. Such conductive area, DC Schlumberger soundings are very difficult to apply since the measured voltages are proportional to the resistivities.

The use of the PROTEM system was very adequate to the ground water survey in the central dry zone because of the following reasons:

① The overall resistivities are very low, sometimes less than one ohm-m values are obtained. In case of Schlumberger soundings, huge currents are necessary for the conductive environments, and often encounter the limitation of the equipments.

② Depth to the target layers are deep, sometimes depth of investigations of 300 to 500m are required. To measure up to 500m is not at all problem for the rented PROTEM system. If the SYSCAL system is used for the survey of the same depth, AB/2 of up to 1000m or more would be required and field operation could be very tedious and time consuming for the electrode spacing expansion.

③ Very quick operations are possible. It took about 30 to 50 minutes to layout 100m * 100m square loops, and 10 minutes are enough for the 3 frequency measurements. At KANGYIKON area, we could measure one station with about 70 minutes including transportation time to the next points.

One the other hand, the skills of the computer usage are required and portable computers of reasonable speeds and capabilities are needed. In this training, only two computers were operational, one was from DDA (JICA donation), and other was the one lecture brought from Japan.

5. Summary and recommendations

5.1 Summary

DDA personnel have experiences of the operation using SYSCAL-R2 systems. They had no difficulty using the rented SYSCAL system. But they need more complete understanding of the methods to obtain good quality data. For the interpretation, They need more skill and experiences for the practical analysis. In the mountain side of PYAWBWE township, very resistive structures were obtained from the PROTEM measurements. It is difficult to use the rented PROTEM 57 system since this system is designed to middle to low resistivity area, depth from 10 to 500m. To apply the PROTEM system to such highly resistive area, EM-47 transmitter and high frequency coil are required. The application of the SYSCAL will be much easy to this area, but two dimensional interpretation software will be needed. PROTEM measurements showed the presence of very resistive layers below 30m, and horizontal layer inversion methods could not find any reasonable models because of the inclination of the resistive layers. In this area, two dimensional resistivity mapping techniques will be adequate to find the fractures inside the resistive basement.

Time domain electromagnetic methods were completely new to the DDA personnel. Lectures of several days were not enough for them to reach to the reasonable understanding of the methods, but they are now on the stage that they can measure and interpret by themselves in the conductive area like the Central Dry Zone. To apply the PROTEM system to more resistive zones, more understanding and experiences are required.

They could measure one station with about one hour, and if local people were getting familiar with the way how to layout the loop, about 40 minutes were enough for measuring one station.

5.2 Recommendations

The understanding of the resistivity structures is one of the keys to develop underground water in the Central Dry Zone. Now DDA personnel can access the SYSCAL and PROTEM systems, both of them are very new equipments with high level technologies. Only two DDA personnel can attend this training from the beginning to the last this time, but more engineers should have the knowledge and skill of the use of the systems. It is very important to set up the surroundings of the use of these new geophysical tools. Computers should be used more commonly to interpret geophysical data, Wide range of the knowledge and experiences are necessary to interpret acquired data and to create 2-D and 3-D color presentation charts. Recommendations can be summarized as follow:

① Lectures and practice of the SYSCAL and PROTEM measurements and interpretations for wide range of engineer including hydro geologists, civil engineers , mining engineers and any other engineers who are related to the underground developments.

② PROTEM system is turned out to be very practical for the Central Dry Zone, since very conductive environments create no trouble for the time domain measurements. Resolutions and depth investigations are much superior than DC resistivity soundings.

③ Although PROTEM and SYSCAL systems are robust for the use of harsh environments, periodic use of the equipments are required to maintain the accuracy. To prepare the environments that PROTEM measurements are used before drilling as common as the well logging after drilling.

④ Integration of all possible information including drilling results, Schlumber sounding results done by JICA, DDA and BAJ. PROTEM results also should be included in the data base like GIS system.

THANTSHINKAN - KANGYIKONE - THEPYINTAW - HTANAUNGWIN AREA (NYAUNG U TOWNSHIP)

LOCATION	DATE OF MEASURE;	FILE NAME	LATITUDE	LONGITUDE	ELEVATION (M)	G.W.L (M)	AQUIFER DEPTH(M)	AQUIFER THICKNESS	RESISTIVITY VALUE		COMMENCE
									LOGGING	TDEM	
TSK 01	4.12.2002	TEST 7.RED	21 02.414	94` 55.667	164.8	103.7	170.7				
TSK 02	4.12.2002	TEST 7.RED	2.554	56.066	190.5						
TSK 03	4.12.2002	TEST 7.RED	2.519	56.401	185.9						
TSK 04	4.12.2002	TEST 7.RED	2.466	56.675	186.9						
TSK 05	4.12.2002	TEST 7.RED	2.624	56.905	192.6						
TSK 06	5.12.2002	TEST 7.RED	2.71	57.151	193.6						
TSK 07	5.12.2002	TEST 7.RED	2.724	57.363	203.9						
TSK 08	5.12.2002	TEST 7.RED	2.775	57.569	213.3						
KGK 01	25.11.2002	TEST.RED	2.734	57.496	200.6						
TPT 01	5.12.2002	TEST 7.RED	21` 3.378	57.027	207.8		259				salty water
HNW 01	26.11.2002	TEST.RED	20` 59.144	95` 1.744	357.7		200				

SETSETYO AREA (NYAUNG U TOWNSHIP)

LOCATION	DATE OF MEASURE;	FILE NAME	LATITUDE	LONGITUDE	ELEVATION (M)	G.W.L (M)	AQUIFER DEPTH(M)	AQUIFER THICKNESS	RESISTIVITY VALUE		COMMENCE
									LOGGING	TDEM	
SSY	2.12.2002	TEST5.RED	21` 3.021	95` 7.979	424.1	262.2	355.5				
FLK	2.12.2002	TEST5.RED	3.824	9.058	403.4		329.3				
KT	2.12.2002	TEST5.RED	3.541	10.75	397.4	221	317				
KPT-E	2.12.2002	TEST5.RED	3.207	11.703	450		305				
MKD01	6.12.2002	TEST8.RED	1.23	7.624	479.6						
YPL	6.12.2002	TEST8.RED	6.23	8.631	342.6		262.2				
MGT	6.12.2002	TEST8.RED	6.896	10.05	320.7	215	269.3				
TBK	6.12.2002	TEST8.RED	6.567	6.076	351.2						

CHAUK TOWNSHIP

LOCATION	DATE OF MEASURE;	FILE NAME	LATITUDE	LONGITUDE	ELEVATION (M)	G.W.L (M)	AQUIFER DEPTH(M)	AQUIFER THICKNESS	RESISTIVITY VALUE		COMMENCE
									LOGGING	TDEM	
SANGAN	10.12.2002	TEST9.RED	20` 46.450	94` 58.818	335.3						
SANZU	10.12.2002	TEST9.RED	42.662	59.732	342.7		298.8				no aquifer
NYT	10.12.2002	TEST9.RED	42.565	53.893	265.2		213				
YELAR	11.12.2002	TEST10.RED	40.135	95` 0.540	375						
SHARPIN	11.12.2002	TEST10.RED	47.591	0.937	292.7						
NPT01	11.12.2002	TEST10.RED	50.916	94` 57.989	295						

KOKE - SAKA AREA (MYINGYAN TOWNSHIP)

LOCATION	DATE OF MEASURE;	FILE NAME	LATITUDE	LONGITUDE	ELEVATION (M)	G.W.L (M)	AQUIFER DEPTH(M)	AQUIFER THICKNESS	RESISTIVITY VALUE		COMMENCE
									LOGGING	TDEM	
KOKE01 (TDEM)	12.12.2002	TEST11.RED	21` 36.681	95` 30.999	151.5						
KOKE (TUBEWELL)	12.12.2002	TEST11.RED	35.899	31.013	159.9		13.1	199			too much sand in water
SAKA01 (TDEM)	12.12.2002	TEST11.RED	23.808	22.965	87.1						diff btwn drill and schl
SAKA (TUBEWELL)	12.12.2002	TEST11.RED	23.604	22.971	94.6		30	300			

PYAWBWE TOWNSHIP

LOCATION	DATE OF MEASURE;	FILE NAME	LATITUDE	LONGITUDE	ELEVATION (M)	G.W.L (M)	AQUIFER DEPTH(M)	AQUIFER THICKNESS	RESISTIVITY VALUE		COMMENCE
									LOGGING	TDEM	
PAY	17.12.2002	TEST12.RED	20` 38.087	96` 14.001	221.2		121				mountain, 1st
THABOK	17.12.2002	TEST12.RED	37.281	14.233	225.6						mountain, south
YEPHYU	17.12.2002	TEST12.RED	39.711	13.646	222.2						mountain, north
YBG	18.12.2002	TEST13.RED	39.633	7.57	163.3		200				pressuerized
KYETTE	18.12.2002	TEST13.RED	37.988	5.044	182.3		155.5				salty water
THABYEYO	18.12.2002	TEST13.RED	41.522	1.854	182.5	2	6				new drilling site

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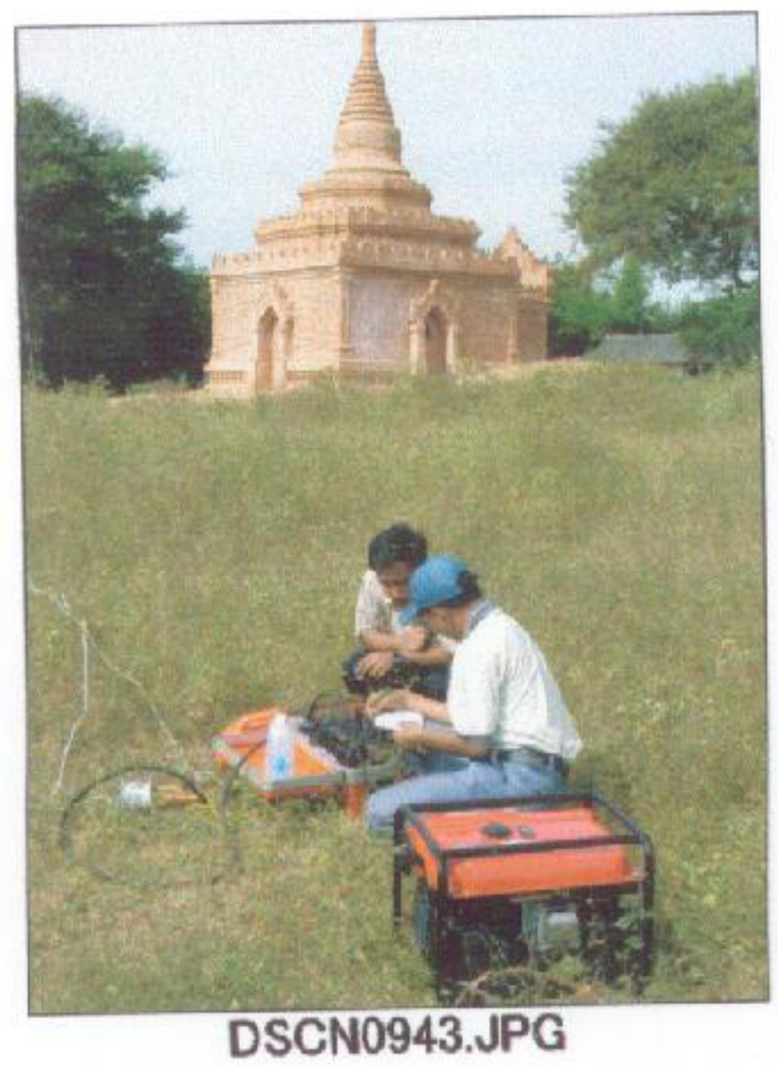

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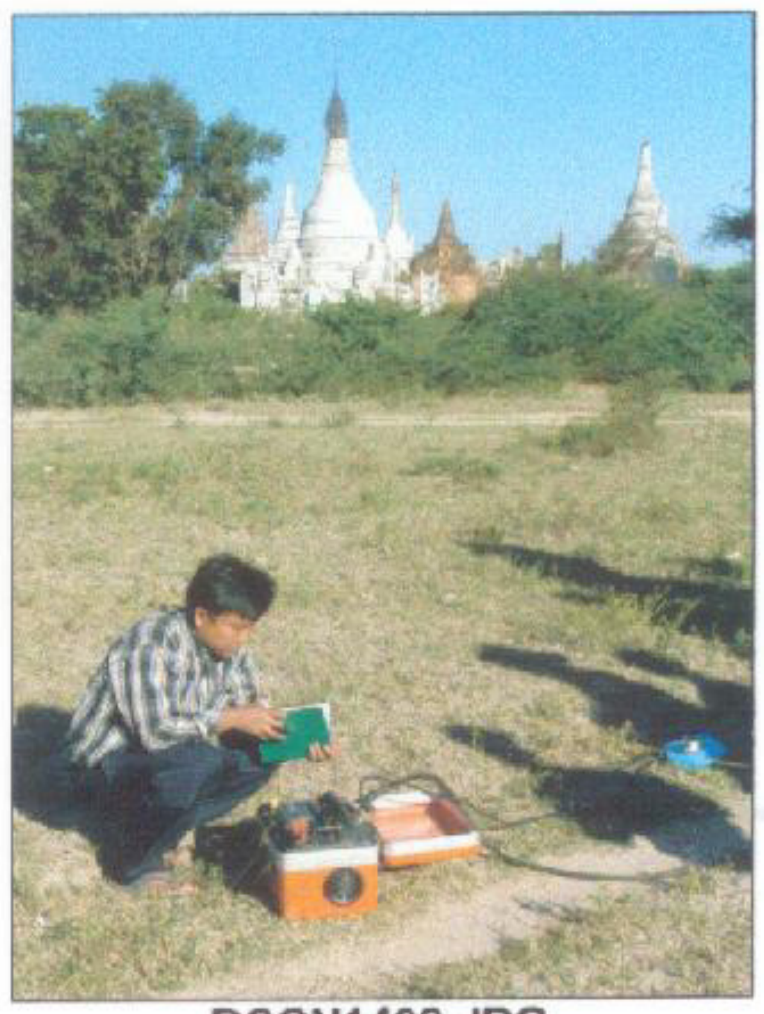

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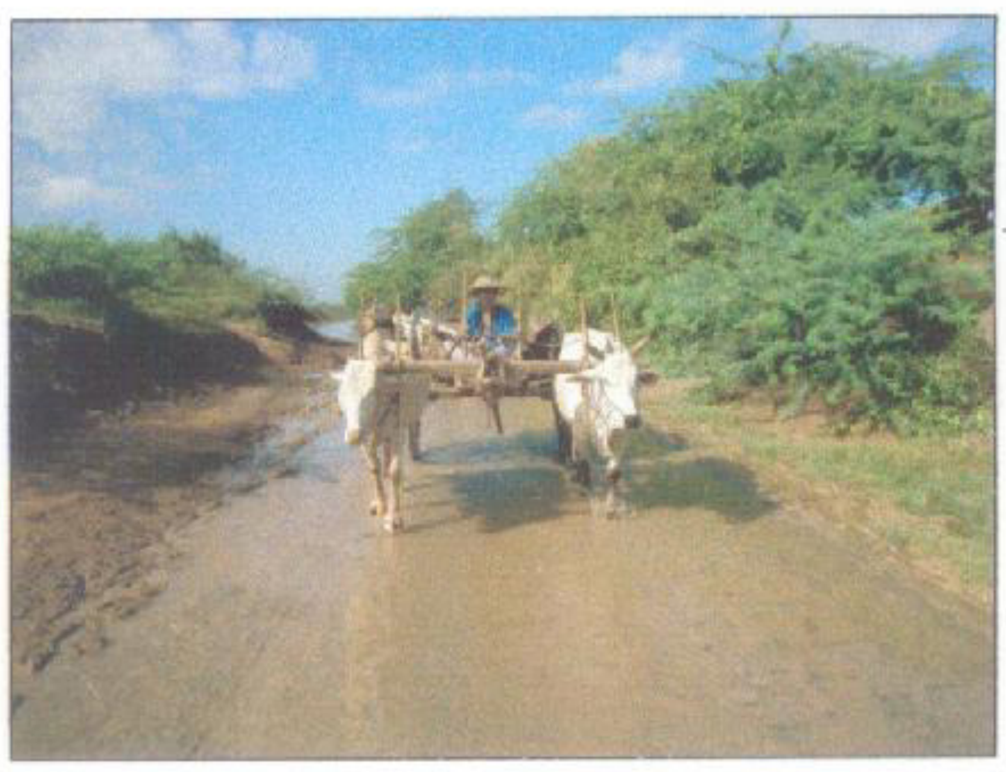

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