添付資料

ワークショップ資料

WS-1 :TEM探査の概要

The Study on Groundwater Resources
Assessment in the Rift Valley Lakes Basin

Transient Electromagnetic (TEM) Survey Workshop

Outline of TEM

Geophysical Survey
Tsugio ISHIKAWA

December 23, 2010

Ministry of Water and Energy
Japan International Cooperation Agency (JICA)

Purpose of the Study

- **The production of hydrogeological maps**
- **To evaluate the groundwater potential of the major aquifers**
- **The establishment of water supply plans for towns of less than about 10,000 people**
- **Mapping Groundwater regions in the area with the aim of improving the Ministry of Water and Energy capacity in water supply planning**

⇩ **Geophysical Survey**

- Understand aquifer structure and geometry
- Provide information on water quality
- Select test well drilling points
- Comparison the electrical and electromagnetic sounding results
- Comparison of the geophysical survey and the well drilling data

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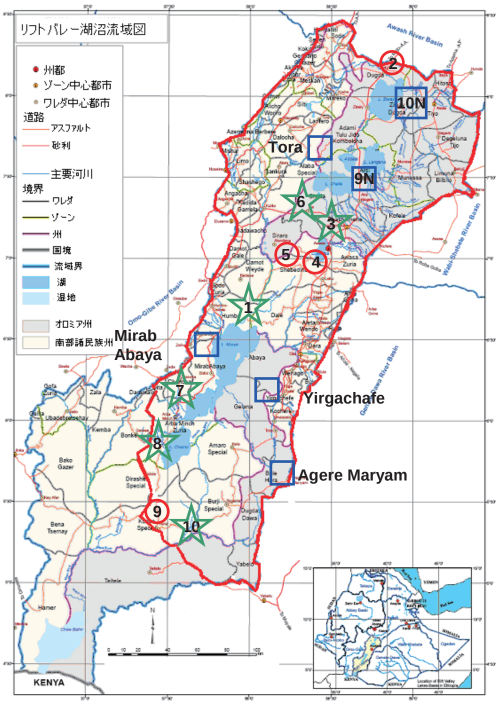
Location of Project Area



Geophysical Sites
Rift Valley Lakes Basin

○ : VES
□ : TEM(TDEM)
☆ : Both Surveys

Drilling number
: Well drilling site
(except No.9 and No.10)

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Progress of the Geophysical Survey

Item of the work	Quantity	2010						
		Mar.	Apr.	May			Nov.	Dec.
	Survey Point							
VES:Vertical Eectrical Sounding	10Sites 100		First Field Survey					
HES:Horizontal Electrical Sounding	15lines, 7275m							
							Second Field Survey	
TEM:Transient Electromagnetic survey	12Sites, 50							

Geophysical methods for Groundwater Exploration

Classification of Electrical Methods

Electrical Methods
- Electrical
- Electromagnetic

What does geophysics detect?

- ◆Electrical conductivity
  - Presence of conductive materials
  - Clays versus sands and gravel
- ◆Magnetic susceptibility
  - Amount of magnetic minerals
  - Volcanics versus sediments

Electrical Soundings

WS-1 ：TEM探査の概要

Measurement Instrument
(Resistivity)

STING R1
Output current : 1～500mA

Electrical Properties

High Resistivity - Low Conductivity Materials

- fresh water
- sand or gravels
- sandstone bedrock
- limestone bedrock

Low Resistivity - High Conductivity Materials

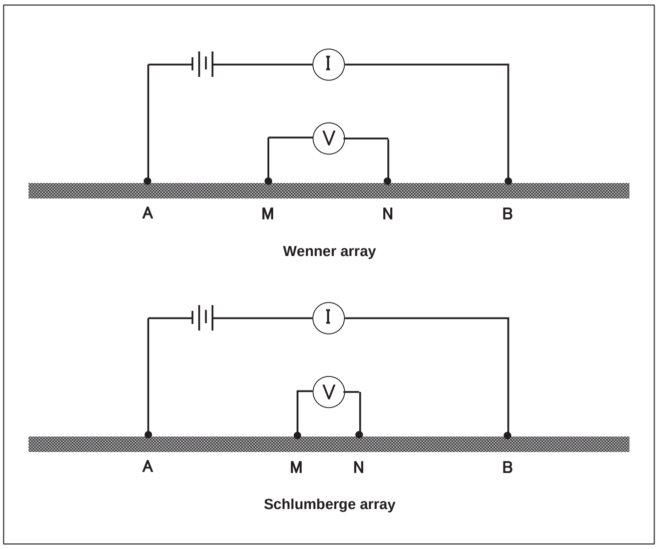
- clays or shale bedrock
- saline water
- sands and gravels saturated with saline water

WS-1 :TEM探査の概要

Quantity of Electrical Soundings

Region	Well drilling site No.	Site area	Total number	
			Vertical Electrical	Horizontal electrical
Oromia	2	Berta/Meki	10	1line, 500m
	3	Oyne-Umbure -Chefo	10	1line, 500m
	10	Brindar	10	3lines, 1500m
SNNPRS	1	Abaya Chokare	10	2lines, 775m
	4	Chancho	10	1line, 500m
	5	Fango Damot	10	1line, 500m
	6	Lajo/Yaye	10	1line, 500m
	7	Arbaminch	10	2lines, 1000m
	8	Walesa	10	1line, 500m
	9	Beresa	10	2lines, 1000m
Total	10	10	100	15lines, 275m

Electrode Configuration



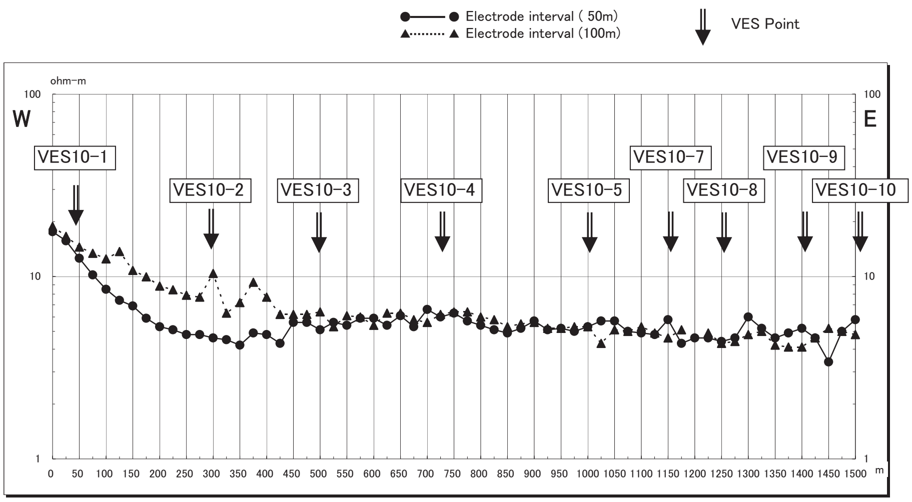
HES
(Horizontal Electrical Sounding)

↓

VES

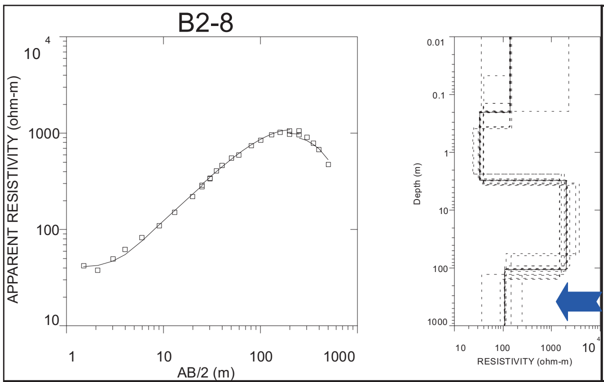
(Vertical Electric Sounding)

WS-1 :TEM探査の概要



Apparent resistivity profile by horizontal electrical sounding (BH10)

Interpretation by inversion



1st-2nd:topsoil

3rd:dry pyroclastic(tuffs, volcanic,ash)

4th:Highly weathered / fracture rocks or pyroclastic(water bearing aquifer)

Analytic example of the Electric survey site BH-2 (Berta/Meki) in Oromia region.

The left figure shows the match between the field curve and the theoretical curve computed for the interpreted resistivity structure.	The right figure shows the interpreted subsurface resistivity structure.

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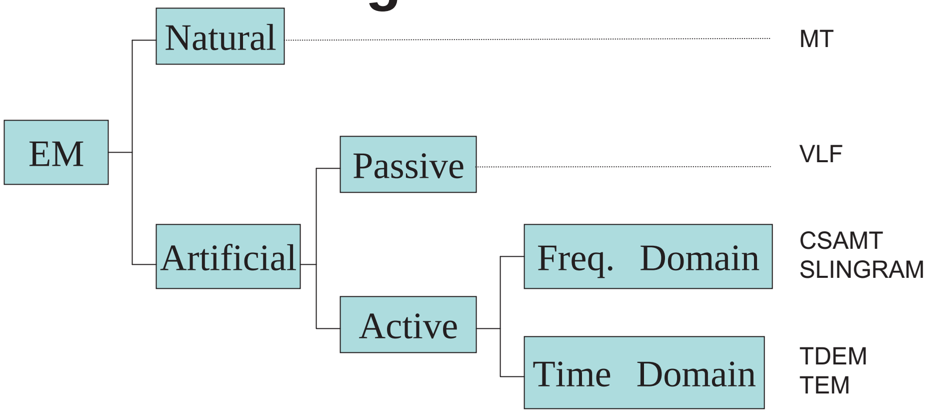
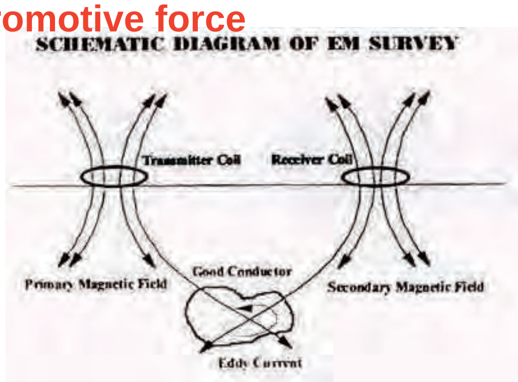
Electromagnetic Methods



- MT Magneto-tellurics
- VLF Very low frequency
- CSAMT Controlled Source Audiomagnetotellurics
- SLINGRAM (This method was originally developed and used in Sweden in the 1930s)
- TDEM Time Domain Electro-magnetic (also TEM)

- **What is electromagnetic method?**
  Geophysical methods
  using electromagnetic phenomena
- **What is electromagnetic phenomena?**
  Currents create magnetic fields
  Change of magnetic field creates
  electromotive force



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Various EM Equipment

VLF Receiver / Transmitter

Operating frequency

15KHz to 28KHz, depending on VLF broadcasting station

Ground Conductivity Meters

EM38

Operating frequency

14.5 kHz

WS-1：TEM探査の概要

Ground Conductivity Meters

Operating frequency

9.8 kHz

EM31

Ground Conductivity Meters

Intercoil Spacings &
Operating frequency

10 m at 6.4 kHz
20 m at 1.6 kHz
40 m at 0.4 kHz

EM34

WS-1 :TEM探査の概要

Slingram

MAXMIN I-8

frequency range of which is from 110Hz to 14.08KHz.

TECHNIQUE USED IN THE FIELD

TDEM
(Time Domain Electro-magnetic Method)
/
TEM
（Transient Electro-magnetic Method）

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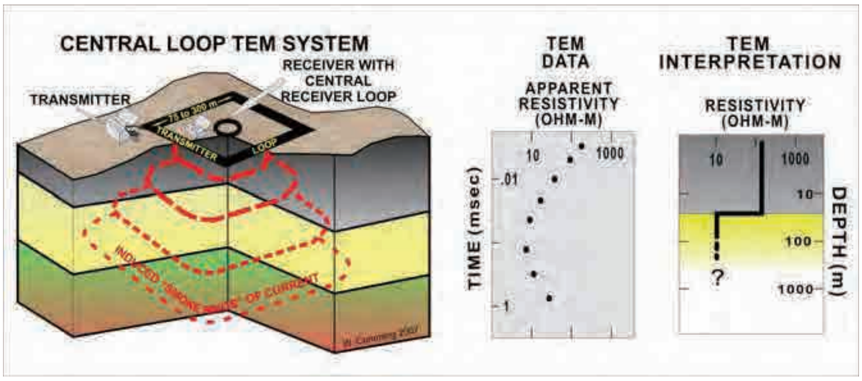
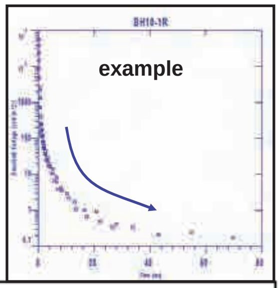
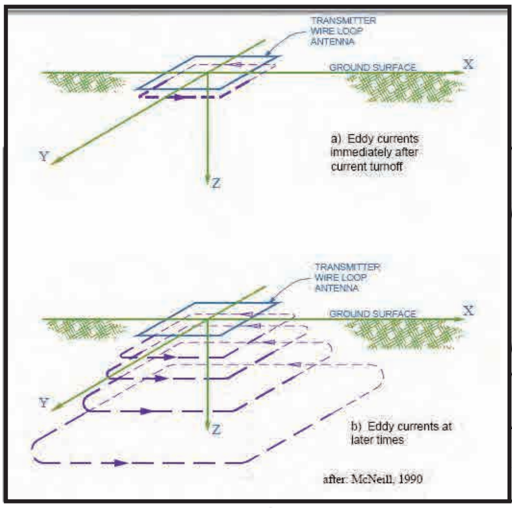
TDEM / TEM

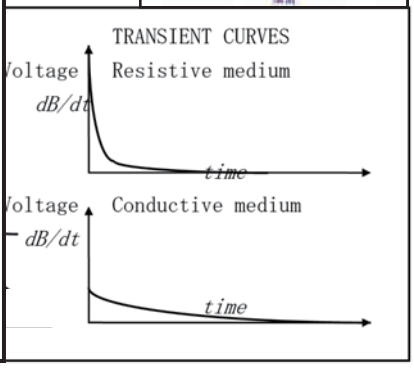


- Pulse current in outer loop, measure signal in inner loop from "smoke rings" of current induced by magnetic field.
- TDEM depth often< 300 m, <<MT
- No electrodes so no static distortion
- Focused so less 2D/3D distortion
- Noisy data or no signal is sometimes misinterpreted

EDDY CURRENTS

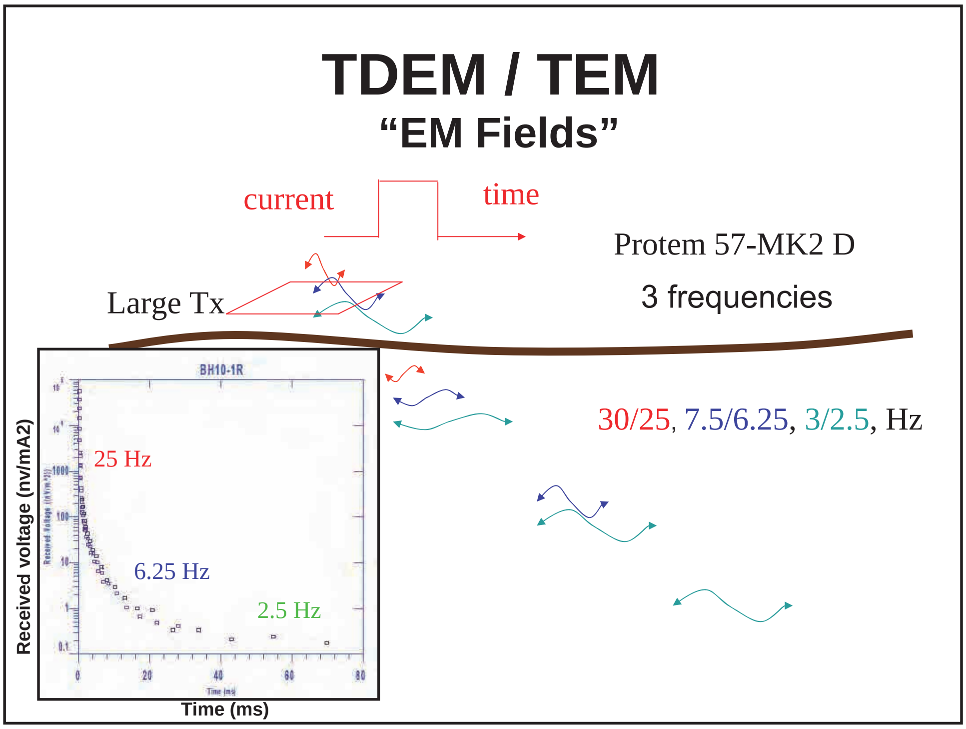


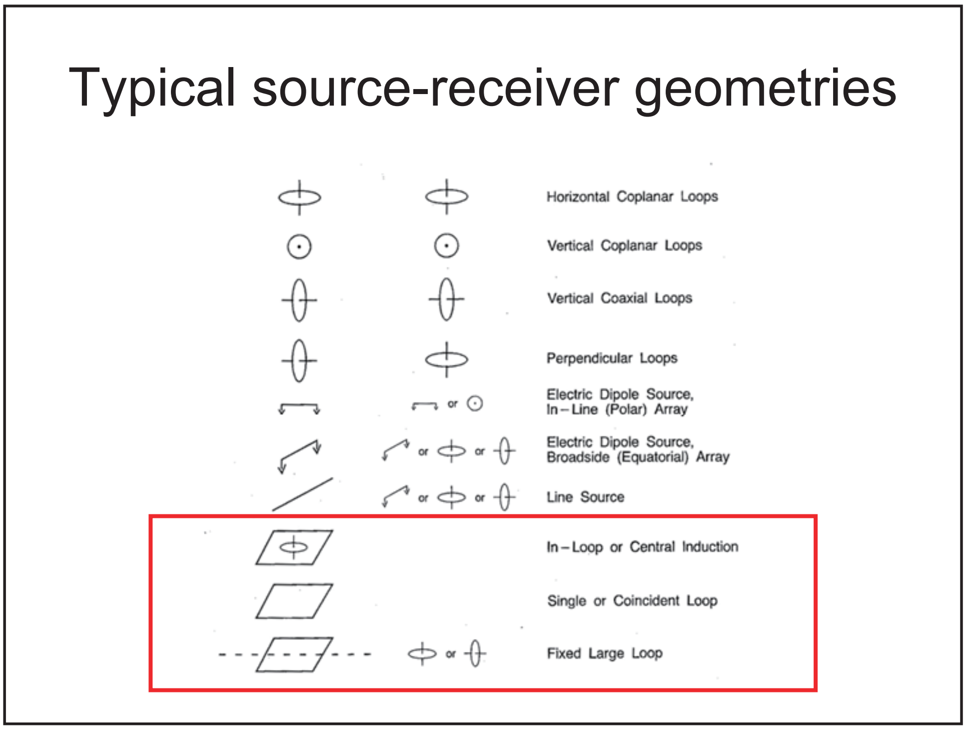




TEM survey configuration and transient curves

WS-1 :TEM探査の概要





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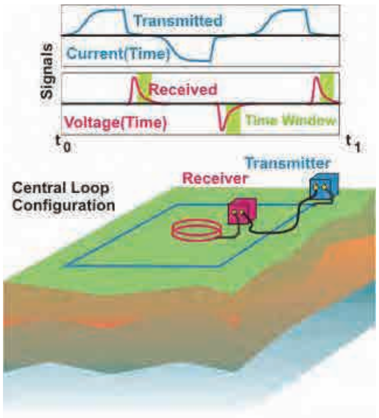
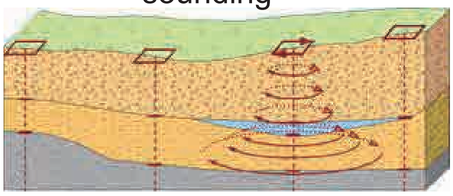
In-Loop or Central induction



Central loop
configuration

sounding



PROTEM TIME DOMAIN EM SYSTEM

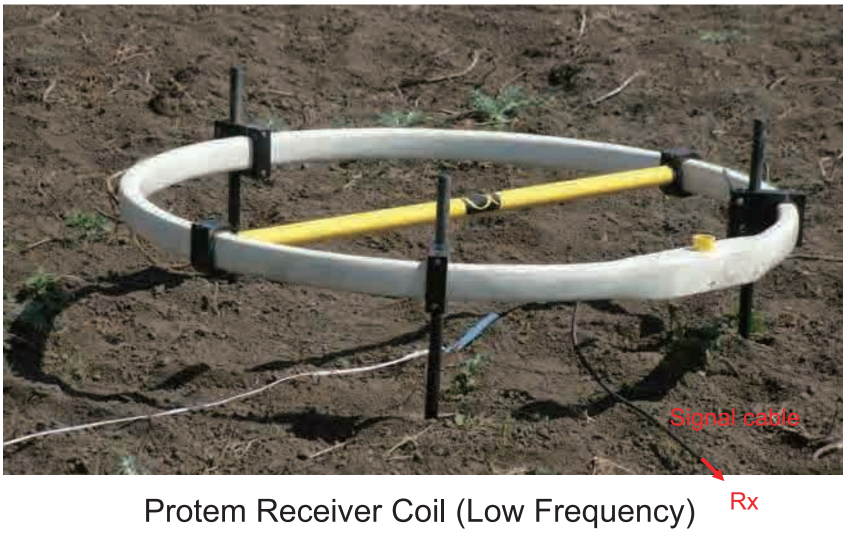
Protem D Receiver

WS-1 : TEM探査の概要

PROTEM TIME DOMAIN EM SYSTEM

TEM57-MK2 Transmitter

PROTEM TIME DOMAIN EM SYSTEM



Protem Receiver Coil (Low Frequency)

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PROTEM TIME DOMAIN EM SYSTEM

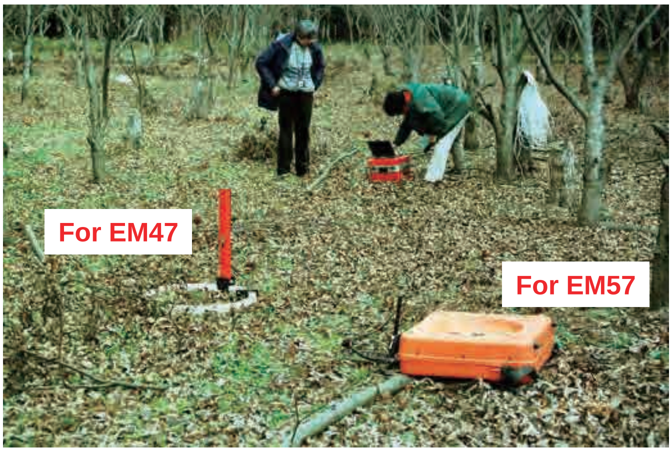
Generator

PROTEM TIME DOMAIN EM SYSTEM

TEM47 Transmitter (Frequency of 75Hz)

WS-1 : TEM探査の概要

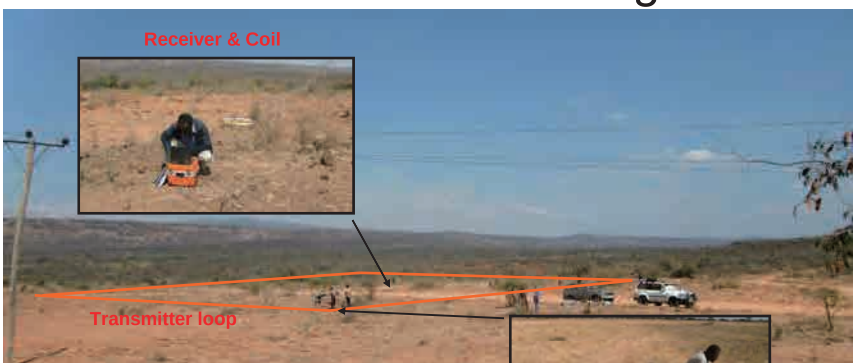
PROTEM TIME DOMAIN EM SYSTEM



Induction Coil

(For EM47:EM57:single component (1D))
(For EM57:(1D) and three component (3D) versions)

Central Induction Coil Configuration



Equipment: Geonics TEM57/PROTEM D
Frequency bands: 25, 6.25, 2.5 Hz
Transmitter loop: 100x100 m, current 9 to 17 A
Receiver loop: 100 coils 1 m diameter
Receiver layout: centre of Tx loop

NOISE

GEOLOGICAL NOISE

- Topography, shallow structures
- Can not improve by source current or stacking
- Serious than environmental noise

ENVIRONMENTAL NOISE

- Noise due to power line, railway, wind, lightning, ground vibration, system noise etc.
- Can be improved by source current, stacking

Summary of TDEM Method

- No galvanic contact required
- No primary field while measuring
- Depth of investigation is controlled by time
- No near field problems
- Less problem of topography, static shift
- Most sensitive to the change of resistivities
- Application to Oil, Geothermal, Civil engineering, Groundwater, Environment
- Many new interpretation programs available
- Several systems are commercially available

WS-1 : TEM探査の概要

Thank you for your attention.

WS-2 ：TEMデータの逆解析

The Study on Groundwater Resources Assessment in the Rift Valley Lakes Basin

Transient Electromagnetic (TEM) Survey Workshop

Data Inversion and analysis

Geophysical Survey
Tsugio ISHIKAWA

December 23, 2010

Ministry of Water and Energy
Japan International Cooperation Agency (JICA)

INVERSION by IX1D v3

(Trademark of Interpex Limited)

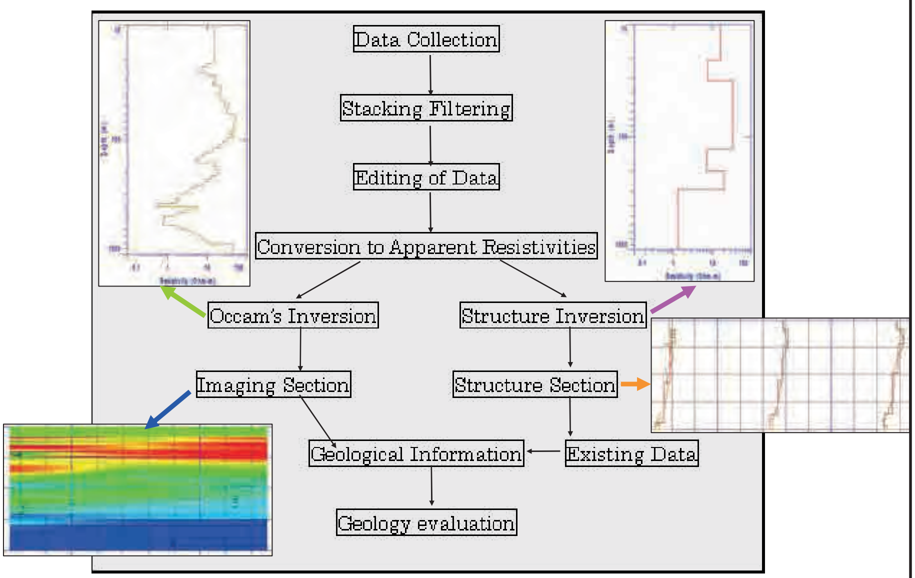
WS-2 ：TEMデータの逆解析

OVERVIEW of IX1D

- **IX1D** is a 1-D Direct Current (DC) resistivity, Induced Polarization (IP), Magnetotelluric (MT) and electromagnetic sounding inversion program

- **TEM** data taken with coincident, central or fixed loop configurations can be inverted.

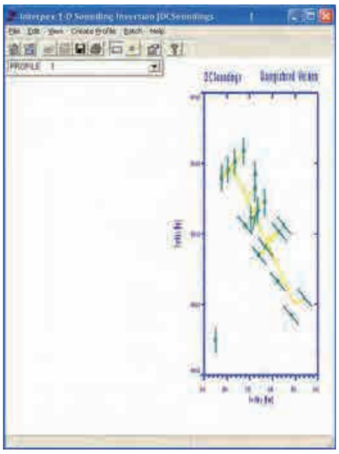
TEM DATA PROCESSING

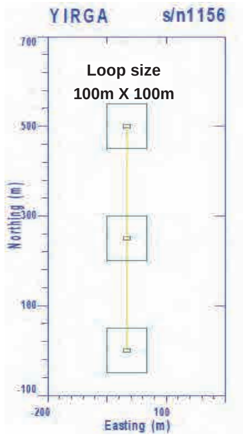


WS-2 ：TEMデータの逆解析

Locations of all soundings

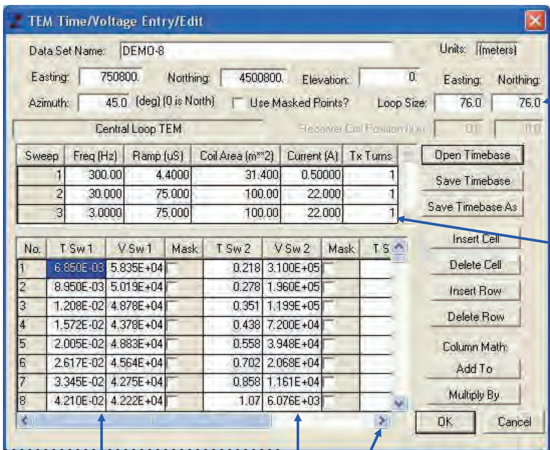
➢Soundings which take place over a distance are displayed along that distance.





➢TEM soundings show the finite size of the source and the receiver is shown as a small box.

TEM Data



Time and Voltage for the first sweep.

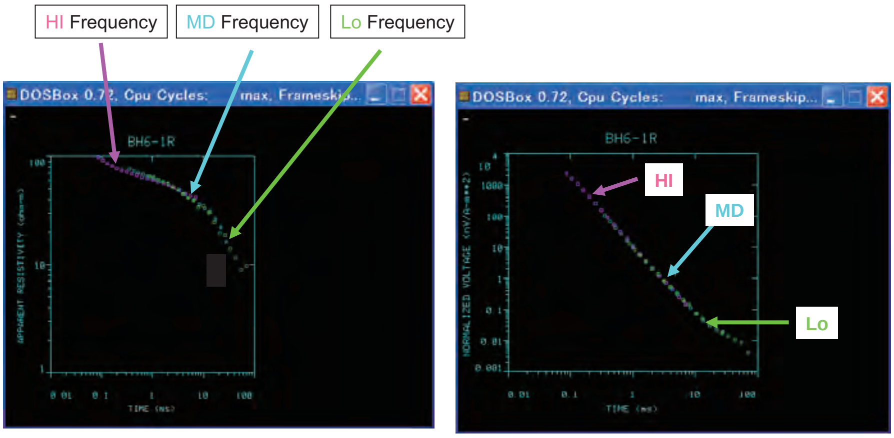
Time and Voltage for the second sweep.

Time and Voltage for the third sweep (the next screen).

- The loop size is the size of the TX loop in the selected units (m or ft). For Fixed Loop data
- there is also a receiver coil position which is relative to the loop center.

- Freq(Hz) : Tx frequency in Hz
- Ramp(μS) : Ramp turn-off time in microseconds
- Coil Area(m**2) : Effective area of the receiver coil
- Current(A) : Tx current in Amps
- Tx Turns : For a multi-turn
- Receiver coil the effective area is the actual area times the number of turns

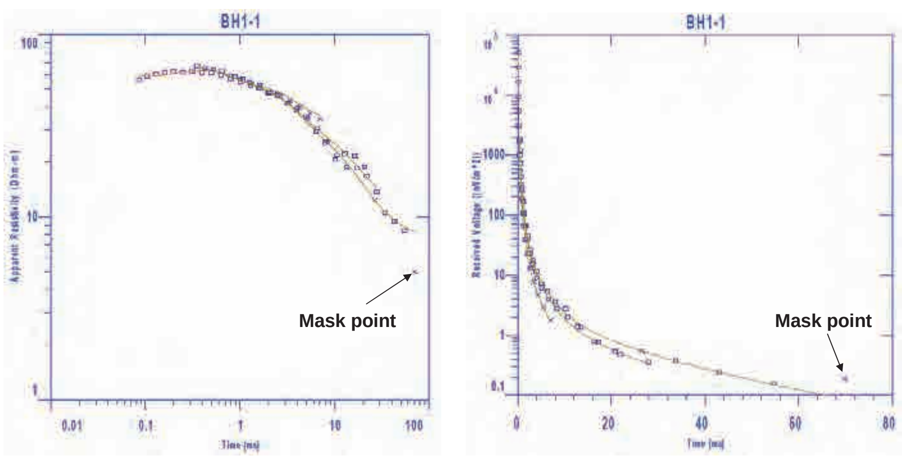
Graphic Display



apparent resistivity　　voltage

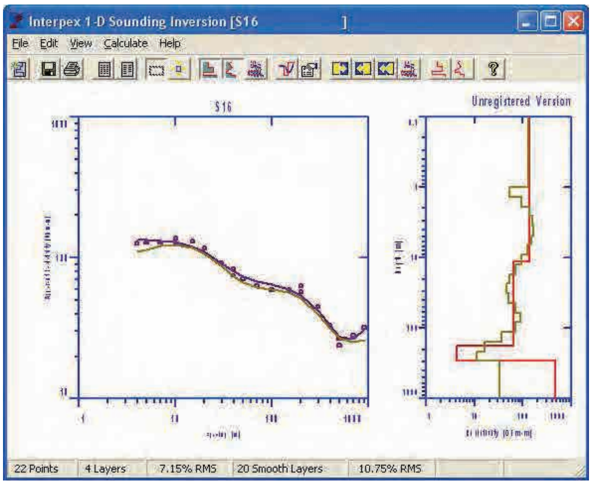
Voltage displays voltage, rather than late time apparent resistivity for TEM Data.

Editing of Data



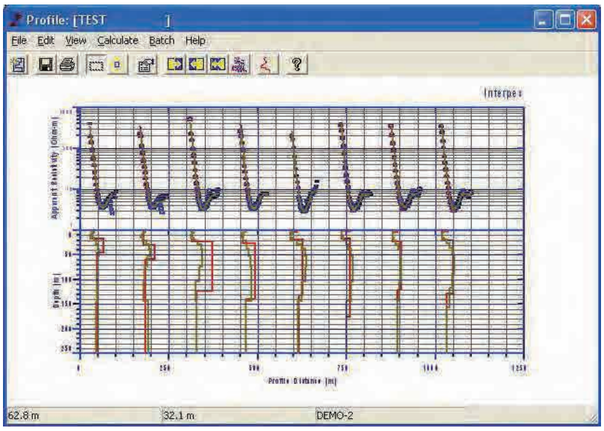
apparent resistivity　　voltage

Graphic Display



Data and equivalent models will be displayed on the model display.

Profile Display Overview

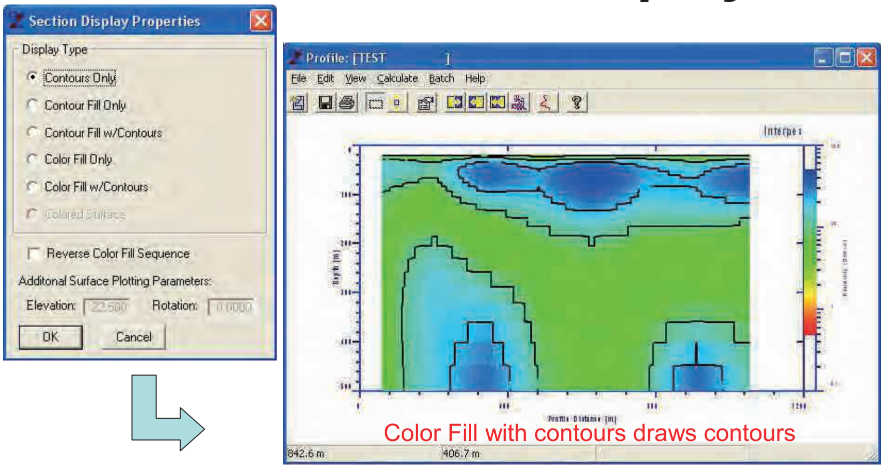


- The Profile Display shows two displays, one for data on top and a second for the model on the bottom.
- Either of these displays can be deselected.

Export data or results or print the graphic

WS-2 ：TEMデータの逆解析

Profile Model Display



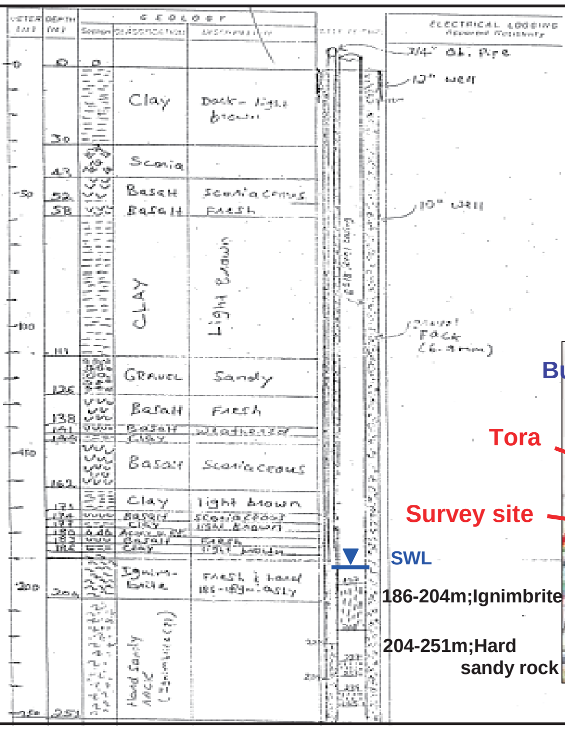
Reverse Color Sequence changes the normal range
of red to blue to blue to red.

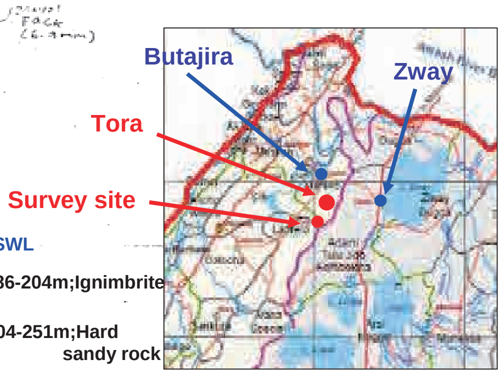
Example of inversion analysis

WS-2 ：TEMデータの逆解析

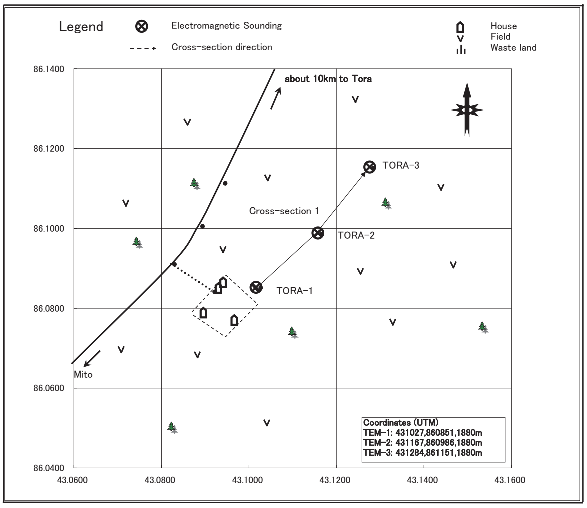
Well data of TORA

Drillied in Aug 28, 1995
Well Depth ; 251m
S.W.L ; 189.10m
Draw Down ; 8.78m
Yield : 3 l/sec



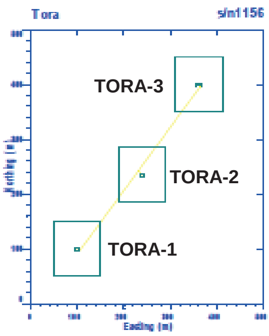


Survey Site near Tora Area

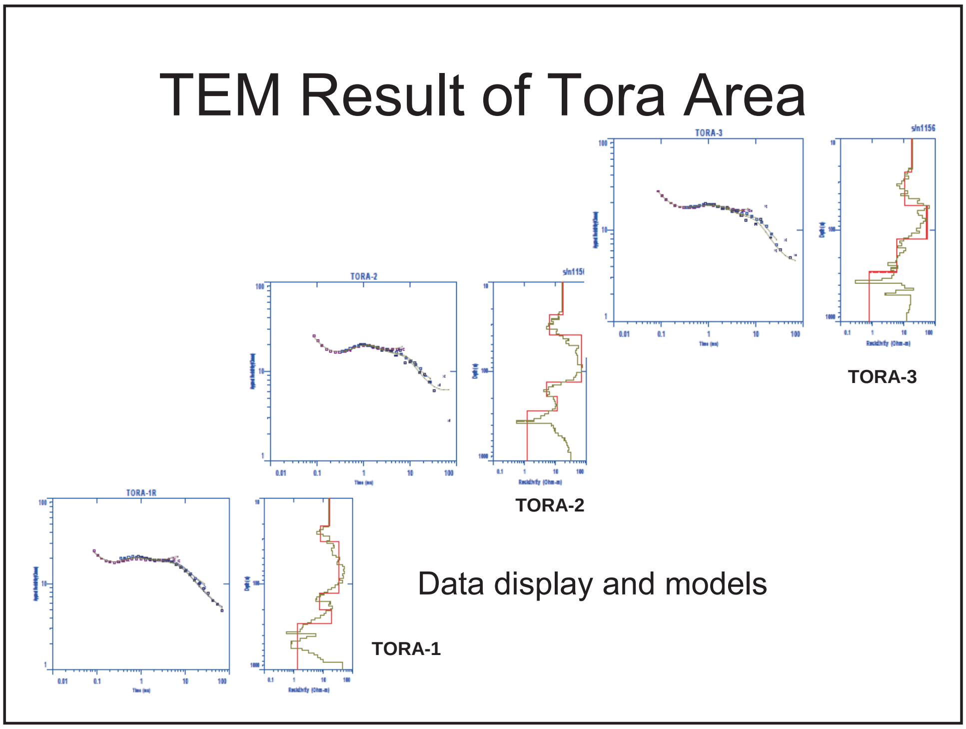


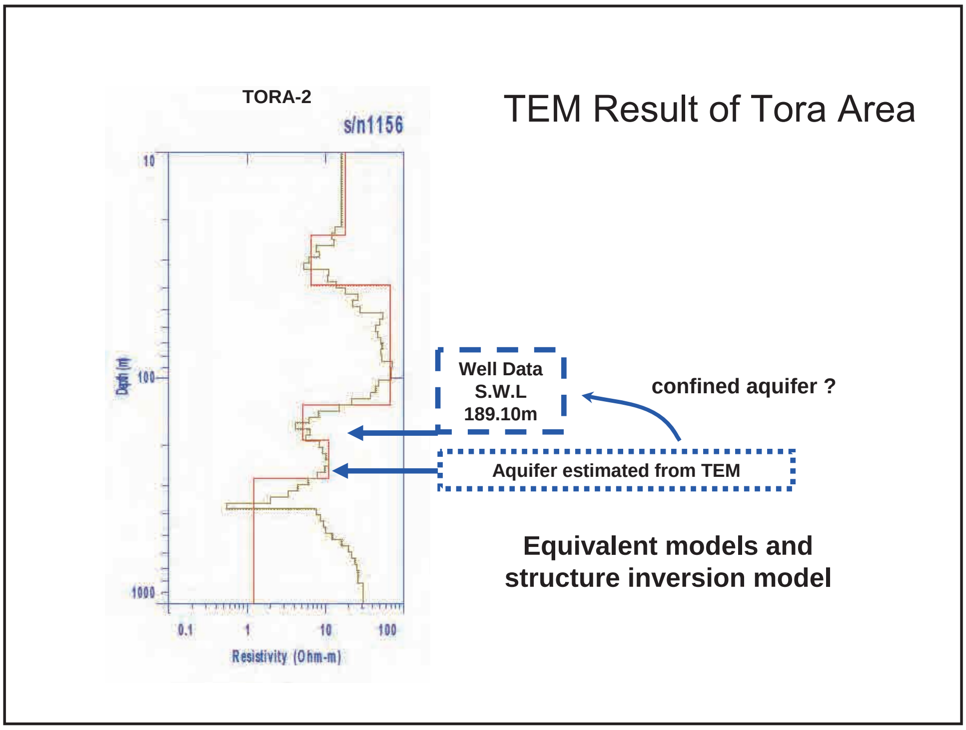
Location map （ Anshebeso Kuchi Village ）

About 10km southwest of Tora



WS-2 ：TEMデータの逆解析





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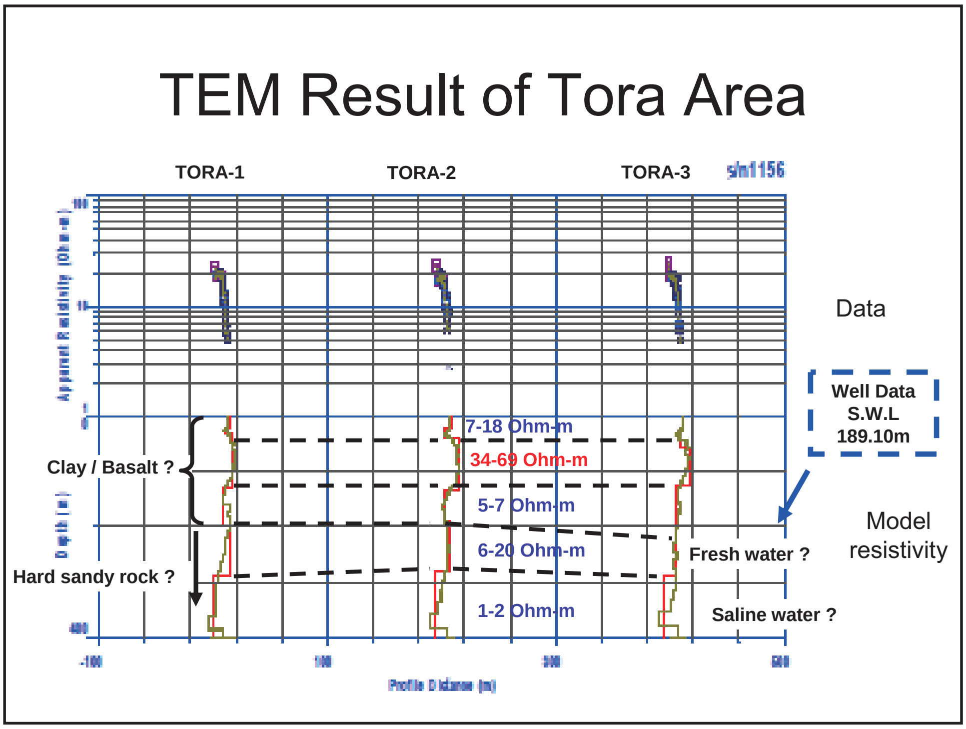
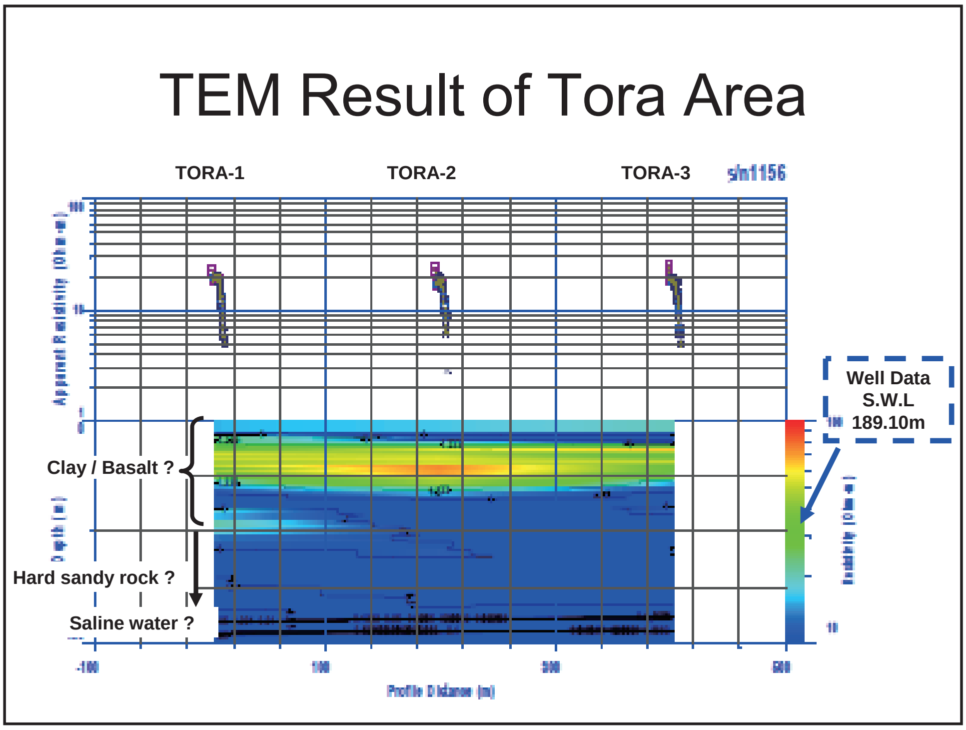
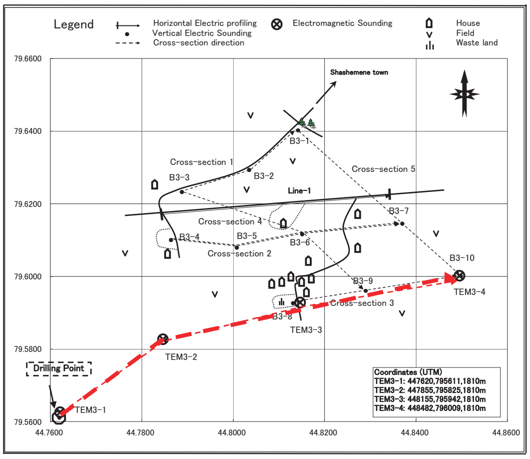




WS-2 ：TEMデータの逆解析

Comparison of the geophysical survey and the well data (BH3)



Location map （Borehole No.3 : Oyne Umbure Chefo）

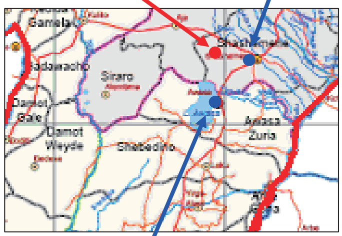
VES : 10 points

TEM : 4 points

Drilling depth : 250m

Survey site
BH 3

Shashemene

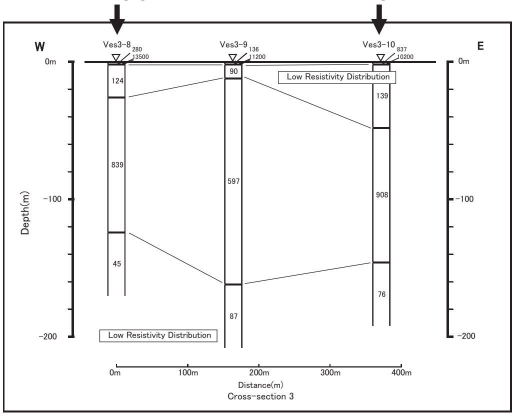


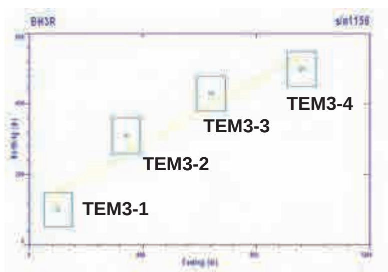
Awassa

VES Result of BH 3

TEM3-3

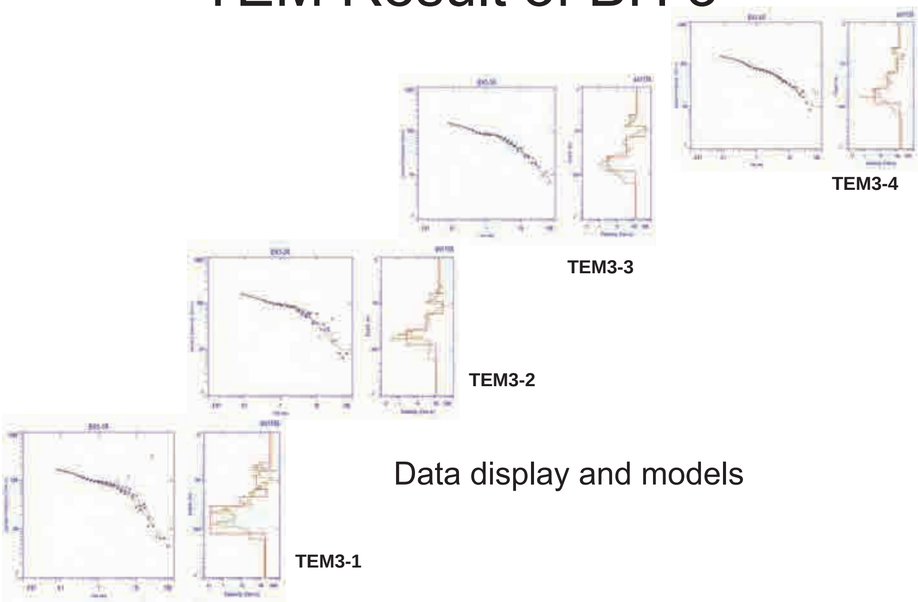
TEM3-4





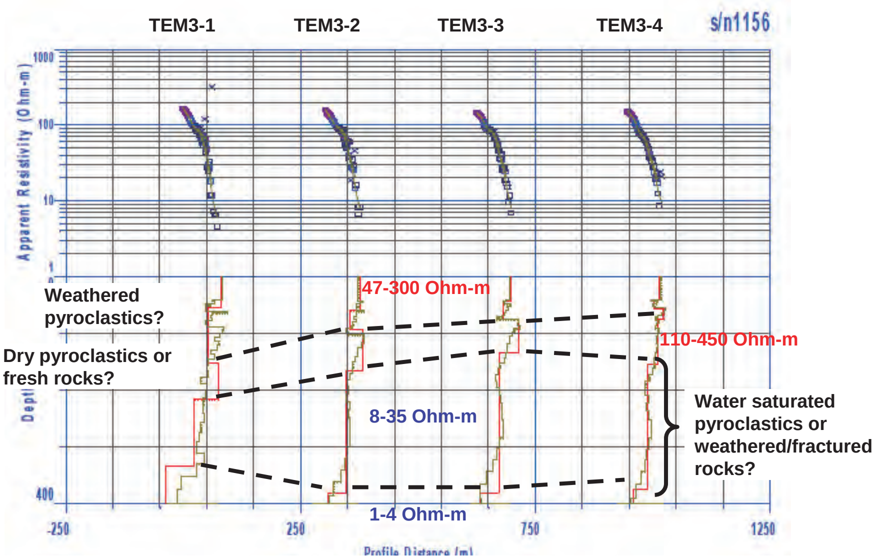
WS-2 ：TEMデータの逆解析

TEM Result of BH 3



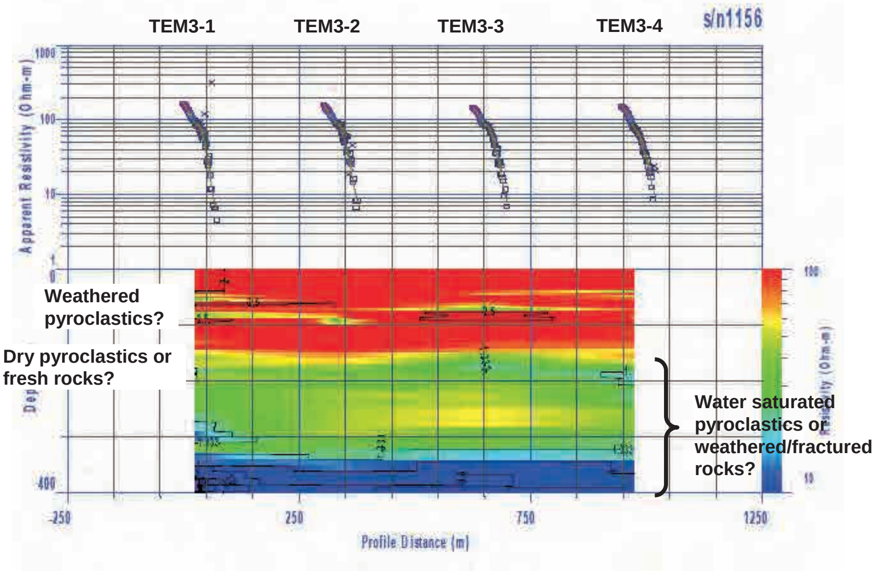
Data display and models

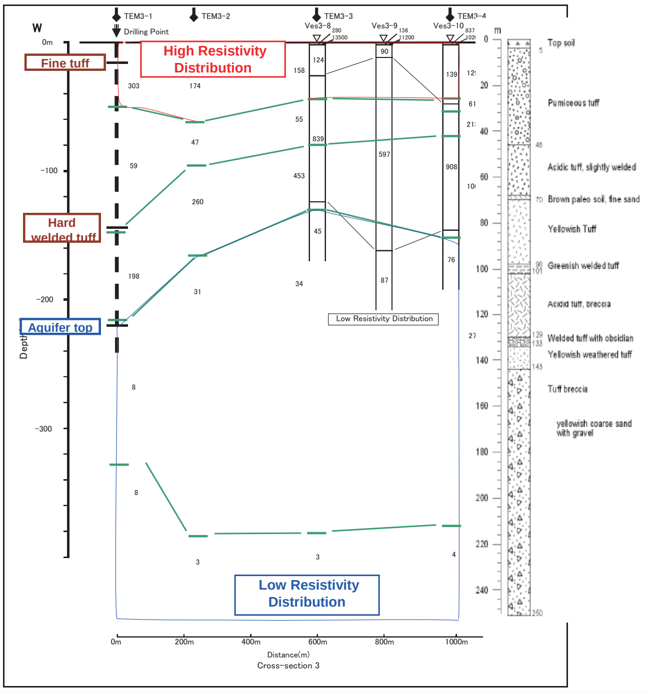
TEM Result of BH 3



WS-2 ：TEMデータの逆解析

TEM Result of BH 3





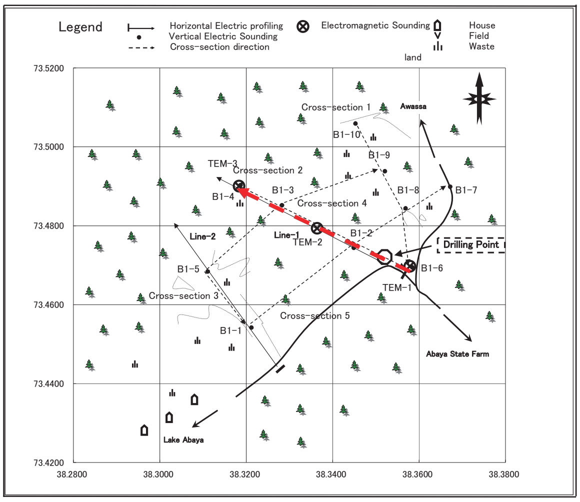
EM Result of BH 3

Result

- Surface is a middle resistivity layer.
- Middle is a high resistivity layer.
- Deepest part is a low resistivity layer.
- As for the above, the result of the electrical sounding and the TEM investigation almost corresponds.
- Aquifer top is the same as the depth of the low resistivity layer of a result of TEM.

WS-2 ：TEMデータの逆解析

Comparison of the geophysical survey and the well data (BH1)

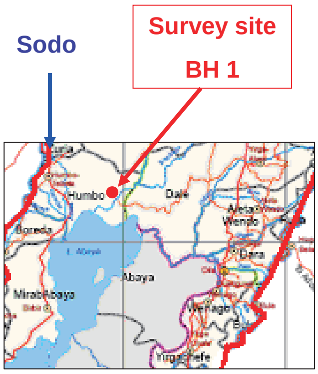


Location map　（Borehole No.1 : Abaya Chokare）

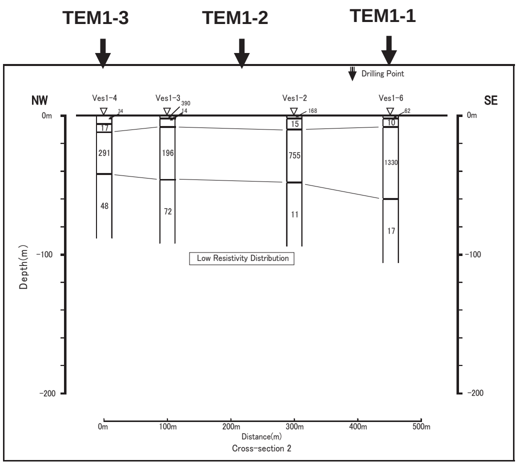
VES : 10 points

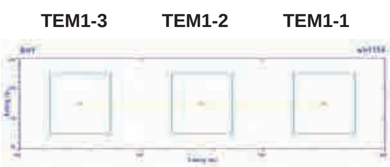
TEM : 3 points

Drilling depth : 150m



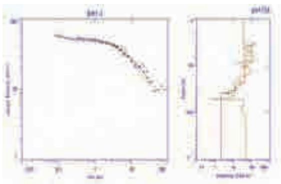
VES Result of BH 1



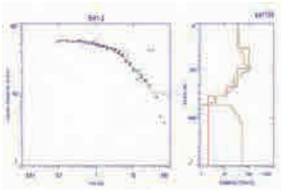


WS-2 ：TEMデータの逆解析

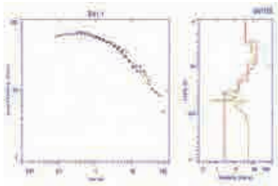
TEM Result of BH 1



TEM1-3



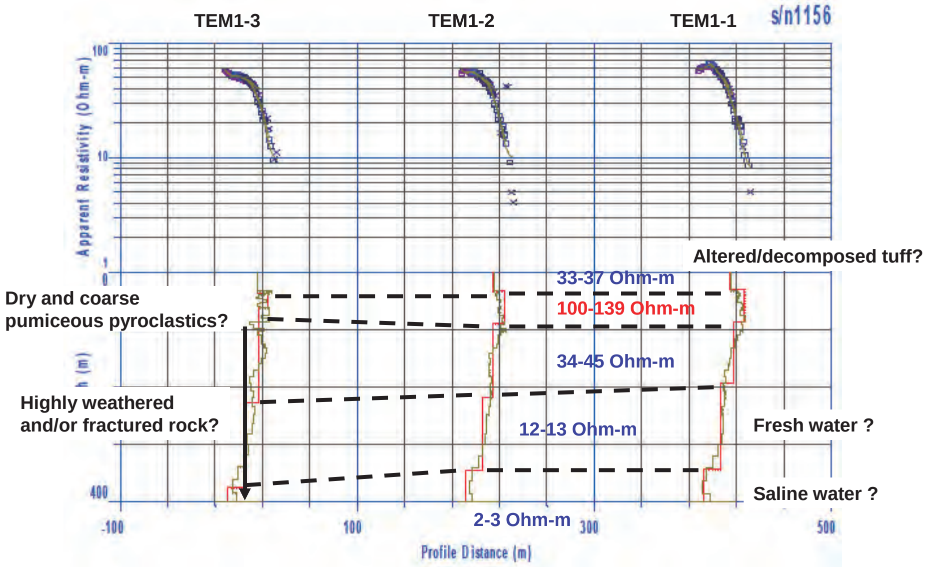
TEM1-2



TEM1-1

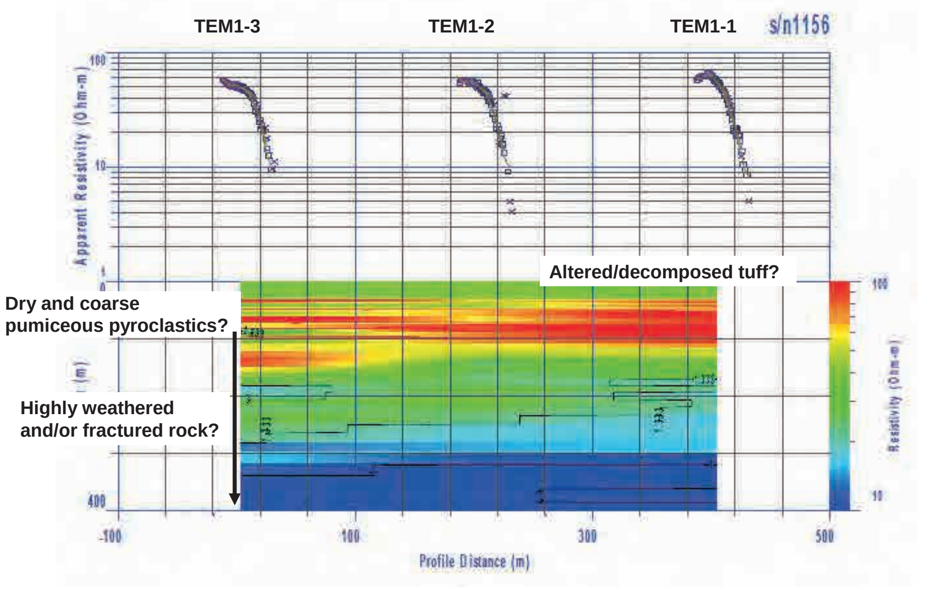
Data display and models

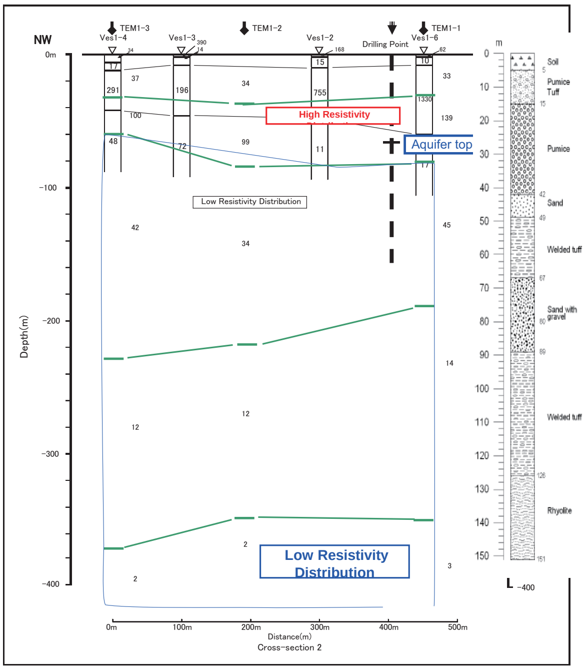
TEM Result of BH 1



WS-2 ：TEMデータの逆解析

TEM Result of BH 1





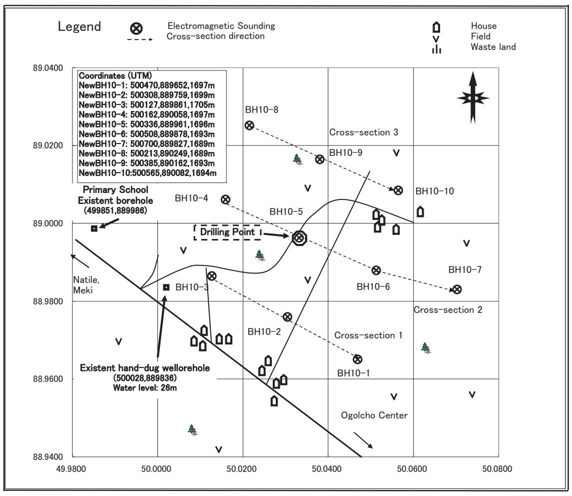
TEM Result of BH 1

Result

- Surface and Middle is a high resistivity layer.
- Deepest part is a low resistivity layer.
- The result of the VES and TEM almost corresponds.
- Aquifer top is almost the same as the depth of the low resistivity layer of a result of TEM.

WS-2 ：TEMデータの逆解析

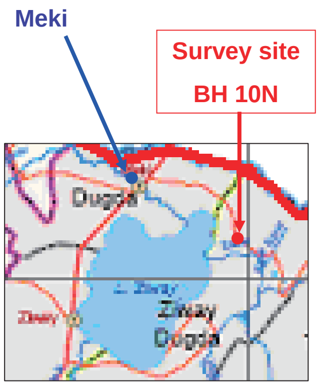
TEM Result of BH10N



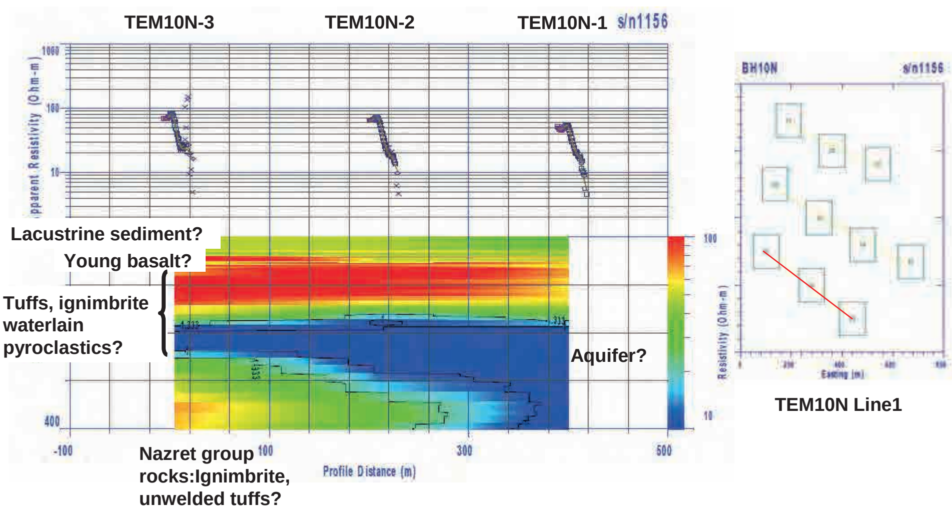
Location map （Borehole No.10N : Ubo Bericca）

Ogolcho Area

TEM : 10 points
Drilling depth : 150m

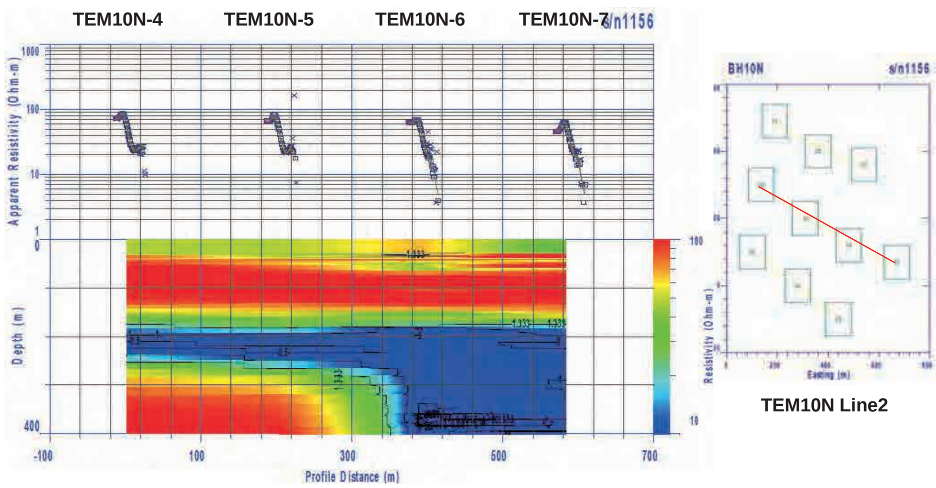


TEM Result of BH10N

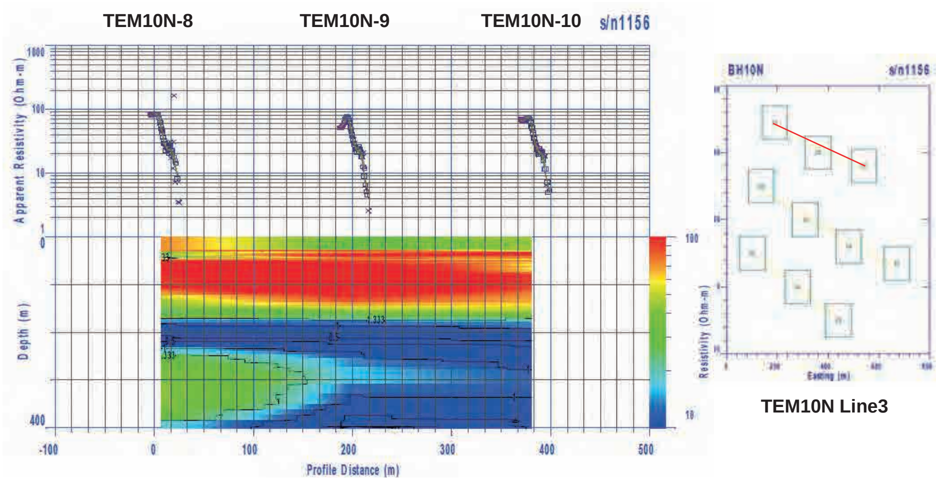


WS-2 ： TEMデータの逆解析

TEM Result of BH10N

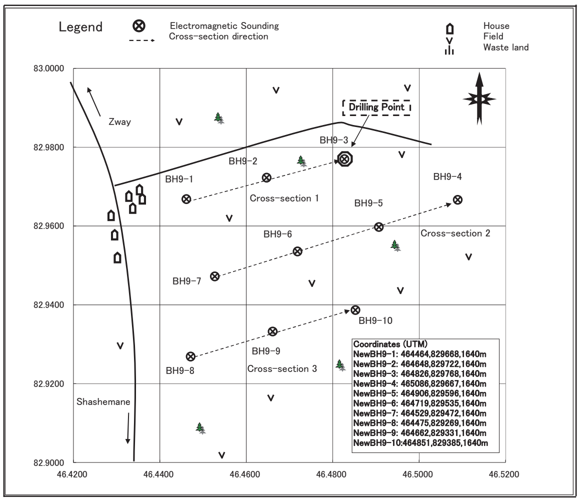


TEM Result of BH10N



WS-2 ：TEMデータの逆解析

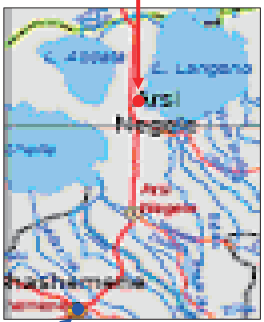
TEM Result of BH9N



Location map （ Borehole No.9N : Dole ）
Langano Area

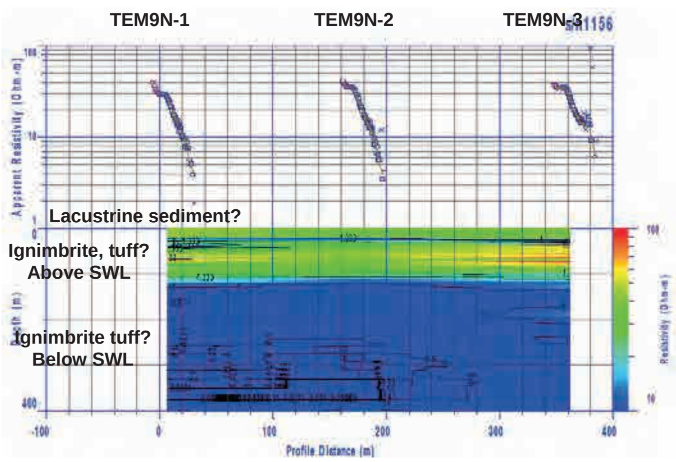
TEM : 10 points
Drilling depth : 150m

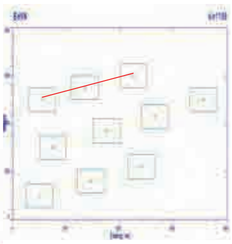
Survey site
BH 9N



Shashemene

TEM Result of BH9N

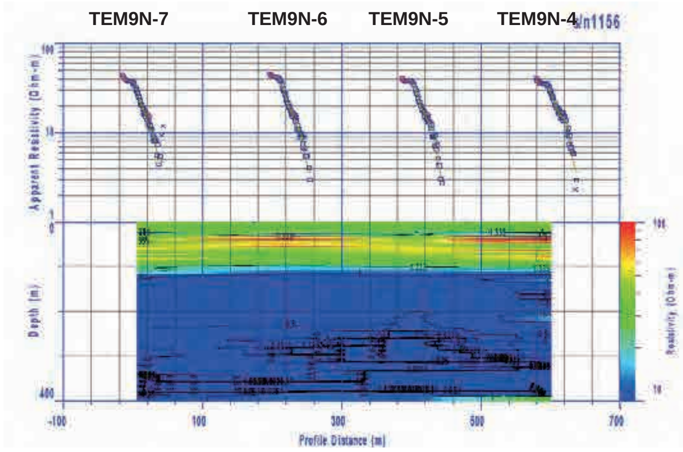


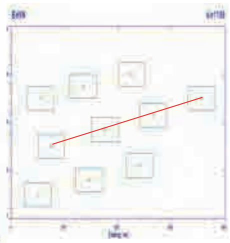


TEM9N Line1

WS-2 ：TEMデータの逆解析

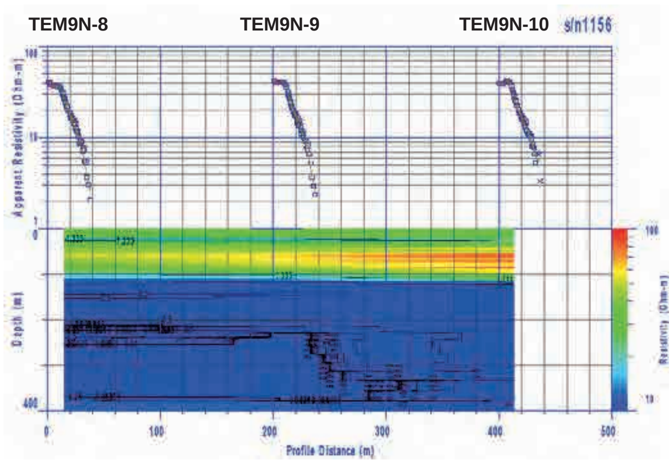
TEM Result of BH9N

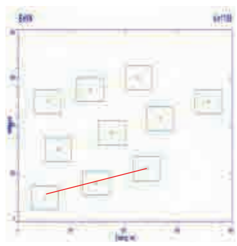




TEM9N Line2

TEM Result of BH9N

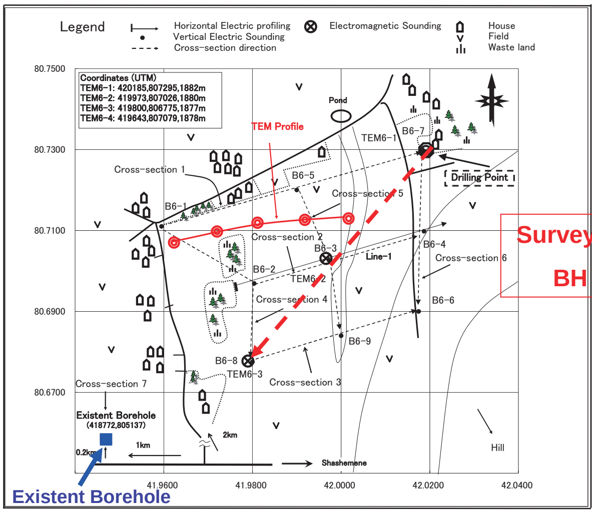




TEM9N Line3

WS-2 ：TEMデータの逆解析

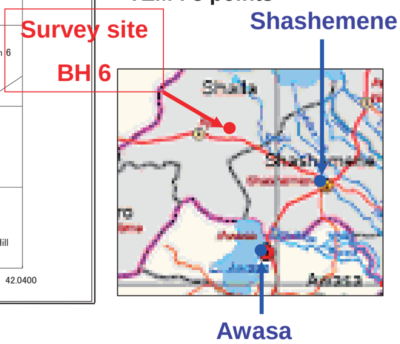
TEM Result of BH6



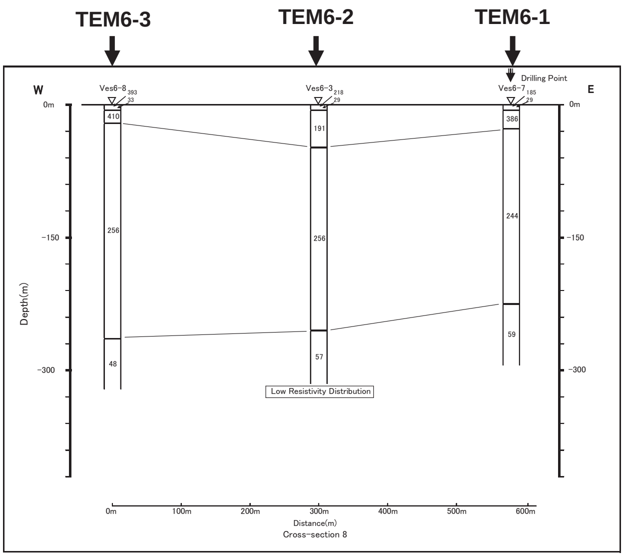
Location map （ Borehole No.6 : Yeye Alaba ）

Well data of Yeye Alaba
Drillied in 2002
Well Depth ; 360m
S.W.L ; 273m
Yield : 7 l/sec
Screen position : 318-360m

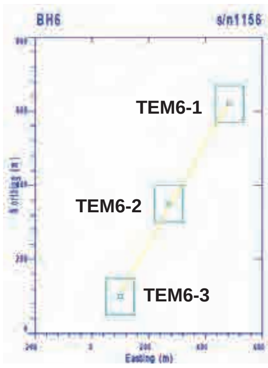
VES : 10 points
TEM : 8 points



VES Result of BH6

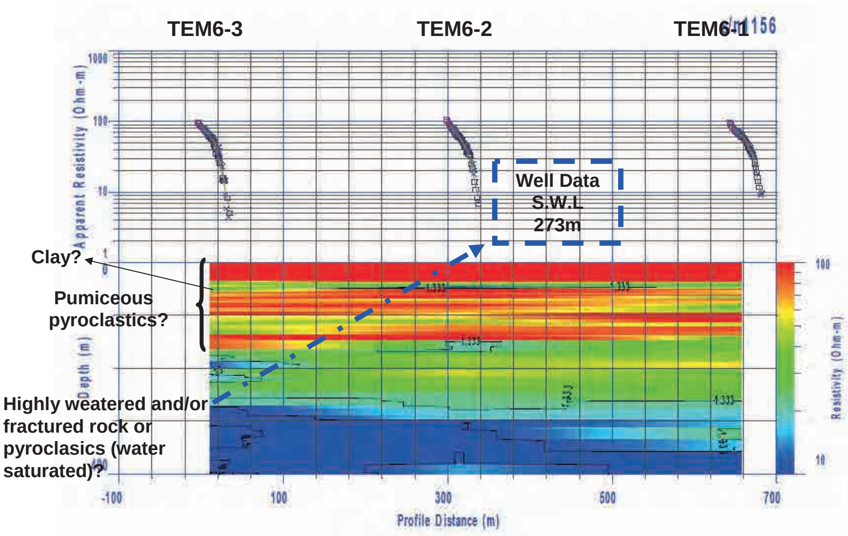


VES : 10 points
TEM : 8 points
Drilling depth : 400m

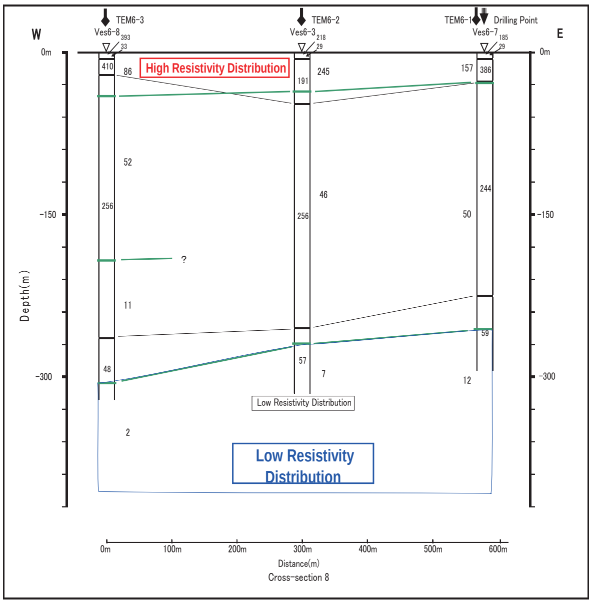


WS-2 ：TEMデータの逆解析

TEM Result of BH6



TEM Result of BH6

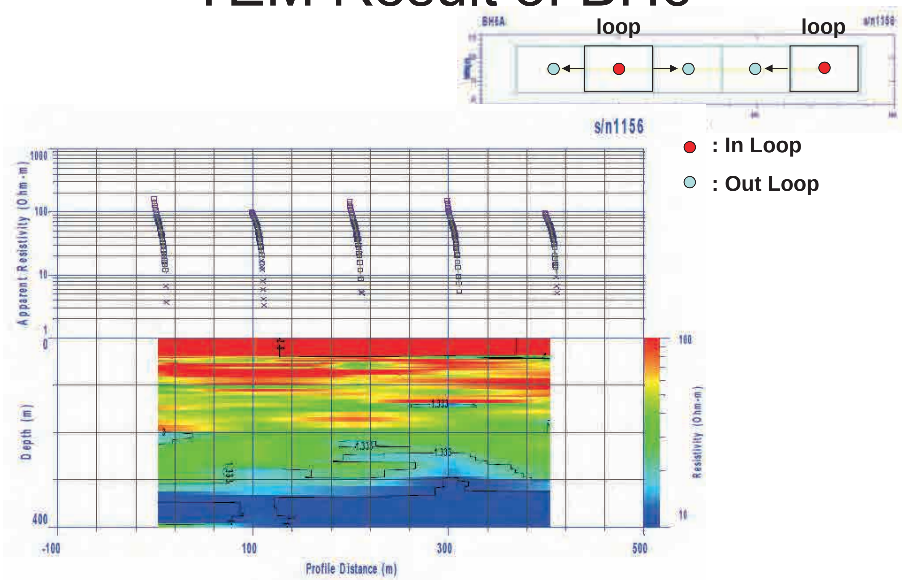


Estimated geology
1st-2nd:topsoil and/or decomposed pyroclastics
3rd-4th:pumiceous pyroclastics
4th-5th:water bearing highly to moderately weathered and/or fractured rock or pyroclastics.

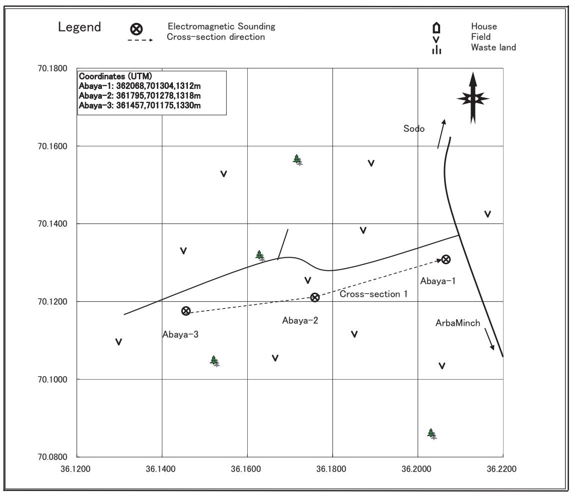
Result
- Surface and Middle is a high resistivity layer.
- Deepest part is a low resistivity layer.
- The result of the VES and TEM almost corresponds.
- Aquifer top is the same as the depth of the low resistivity layer of a result of TEM.

WS-2 ：TEMデータの逆解析

TEM Result of BH6



TEM Result of Mirab Abaya

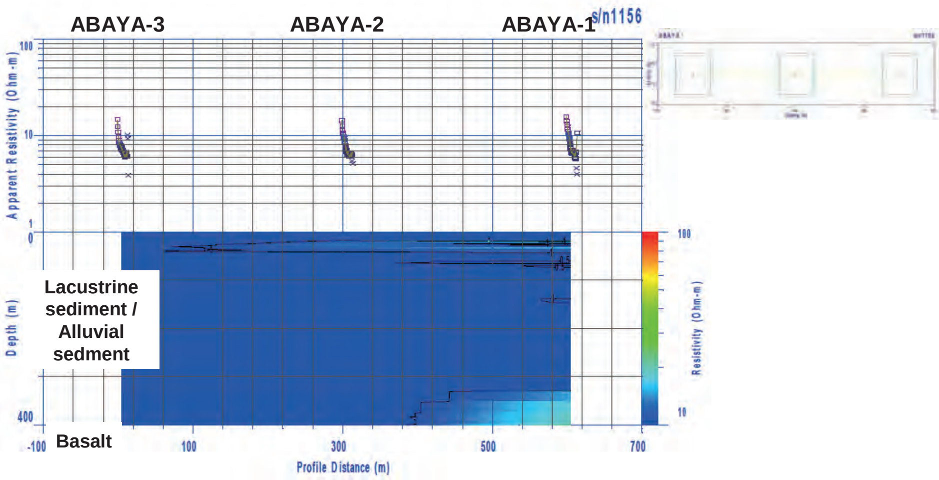


Location map （ Mirab Abaya ）

TEM : 3 points

WS-2 ：TEMデータの逆解析

TEM Result of Mirab Abaya



TEM Result of BH7

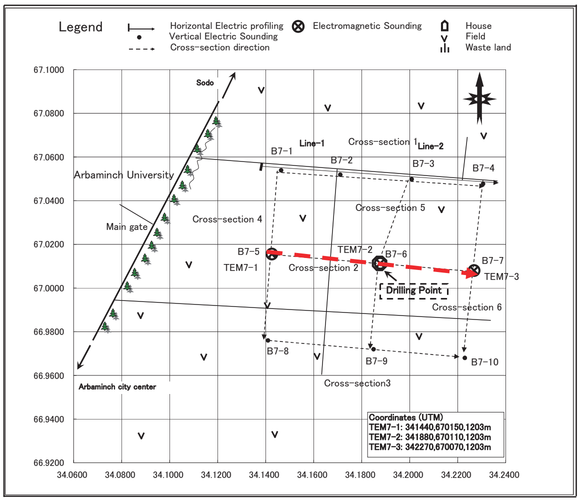
VES : 10 points

TEM : 3 points

Drilling depth : 250m

Survey site

Arba Minch

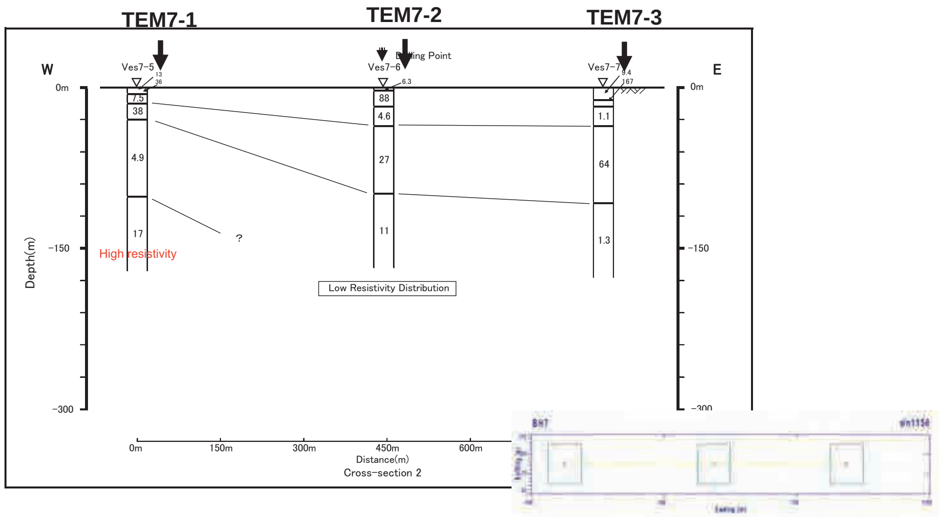


Location map （ Borehole No.7 : Arbaminch ）

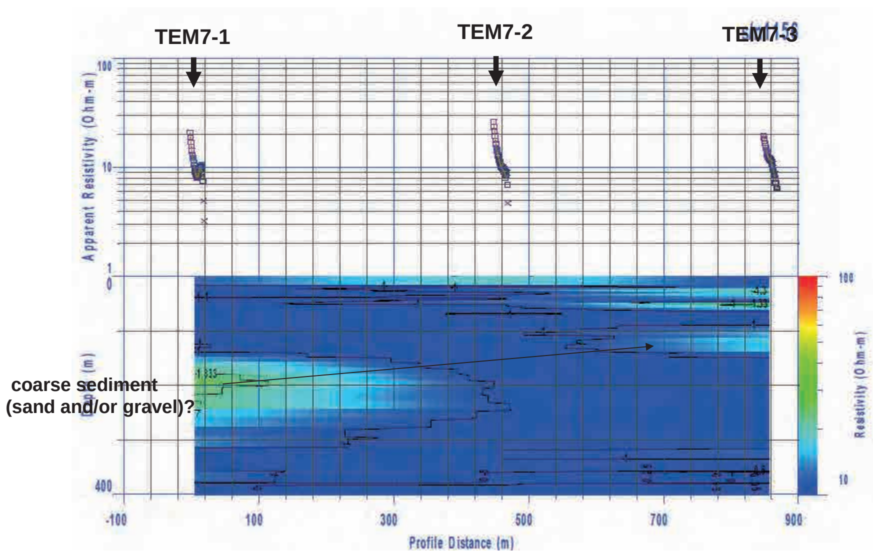
Arba Minch

WS-2 ：TEMデータの逆解析

VES Result of BH7

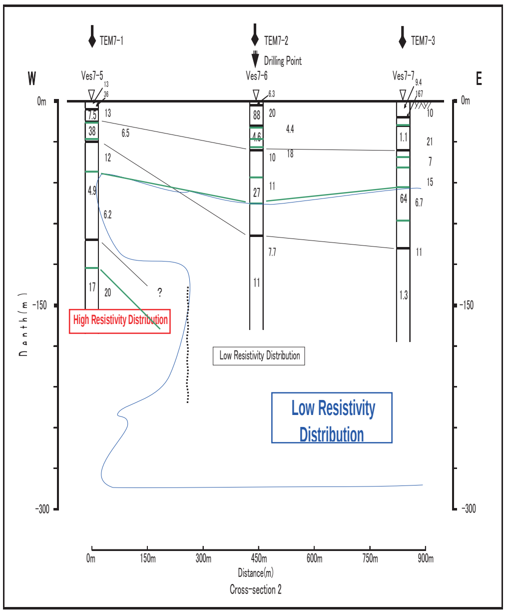


TEM Result of BH7



WS-2 ：TEMデータの逆解析

TEM Result of BH7



Estimated geology
1st-2nd:topsoil, gravel
3rd:sedimentary(relatively coarse sediment)
4th-5th:sediment(clayey, silty or saturated with relatively saline water
6th:bedrock or volcanic rock

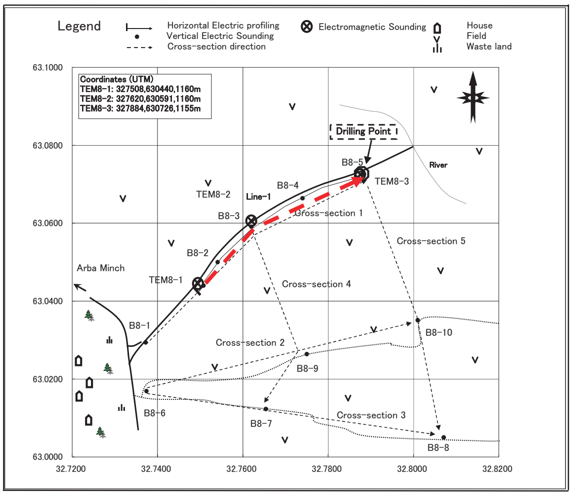
Result
●Deepest part is a low resistivity layer.
●The result of the VES and TEM almost corresponds.
●The discontinuity of the resistivity is recognized between TEM-1 and TEM-2.

TEM Result of BH8

VES : 10 points

TEM : 3 points

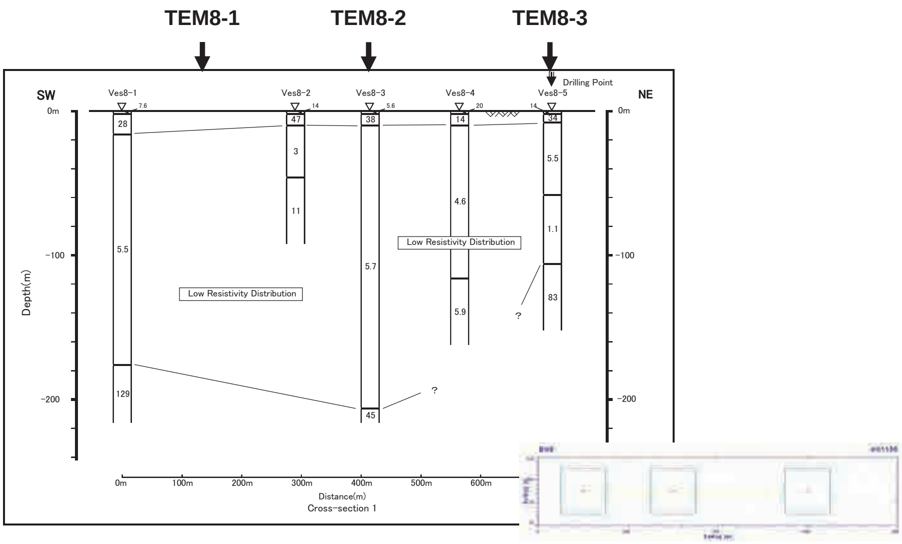
Drilling depth : 250m



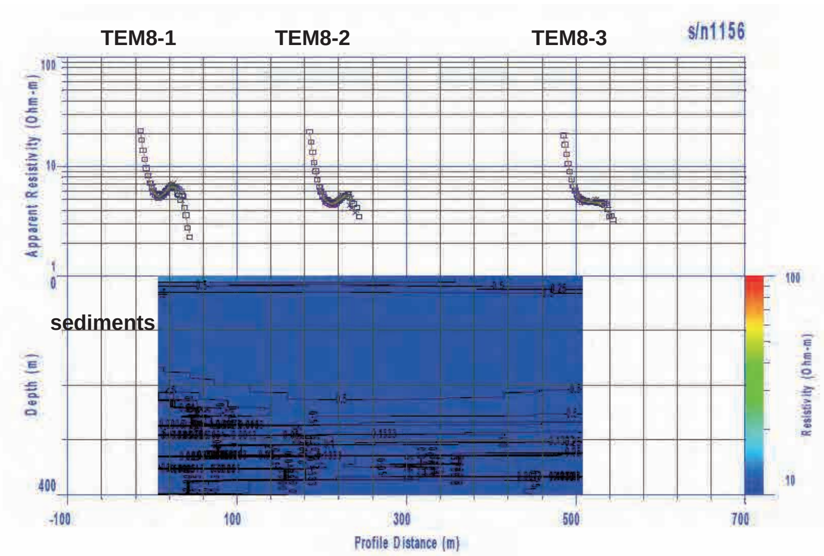
Location map（Borehole No.8 : Walesa）

WS-2 ：TEMデータの逆解析

VES Result of BH8

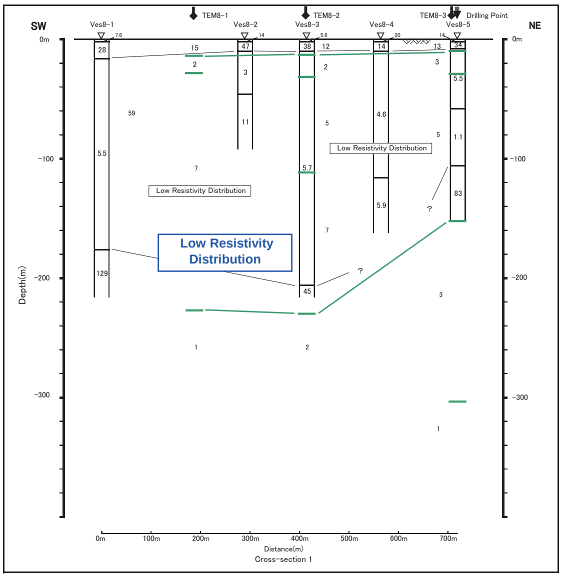


TEM Result of BH8



WS-2 ：TEMデータの逆解析

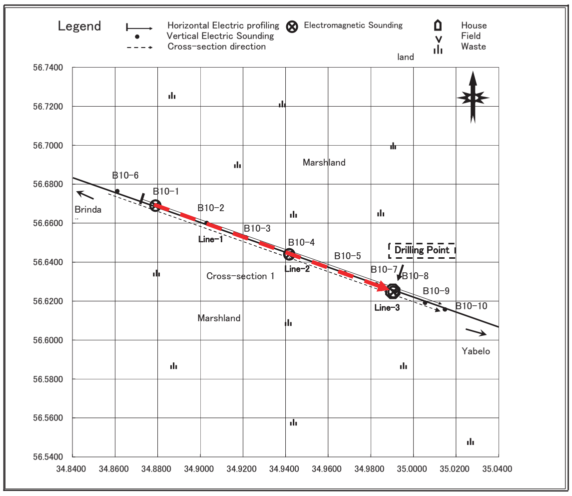
TEM Result of BH8



Estimated geology
1st-2nd:topsoil
3rd:sediments(relatively coarse sediment)
4th:fine grained sediment(saturated with saline water)
5th-6th:bedrock or volcanic rock

Result
- Surface and Middle is a high resistivity layer.
- Deepest part is a low resistivity layer.
- The result of the VES and TEM almost corresponds.
- Aquifer top is the same as the depth of the low resistivity layer of a result of TEM.

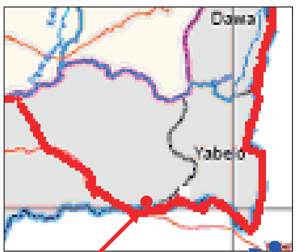
TEM Result of BH10



Location map （ Borehole No.10 : Brindar ）

VES : 10 points

TEM : 3 points

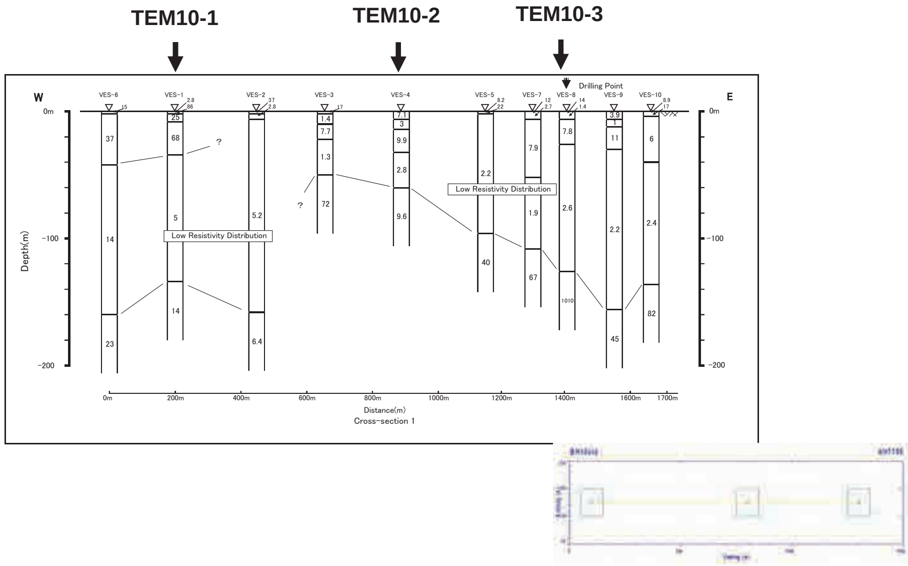


Survey site BH10

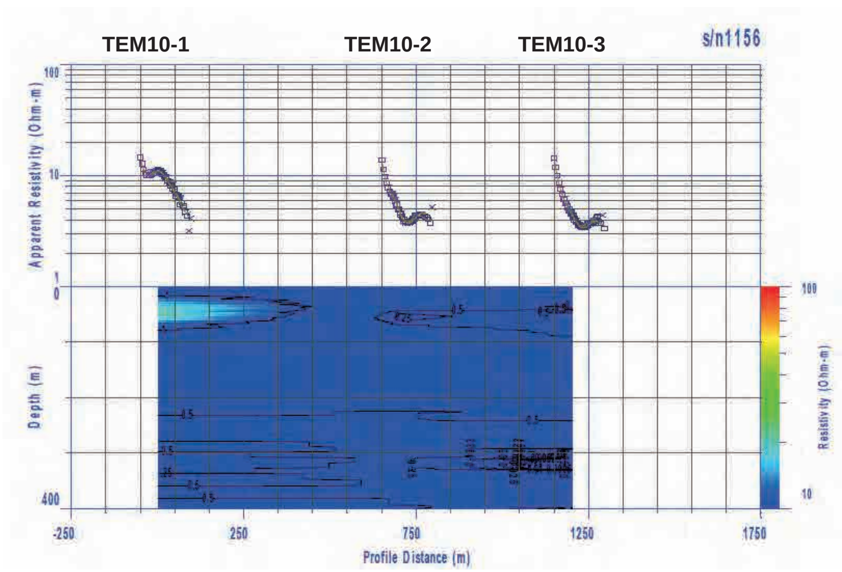
Yabelo

WS-2 ：TEMデータの逆解析

VES Result of BH10

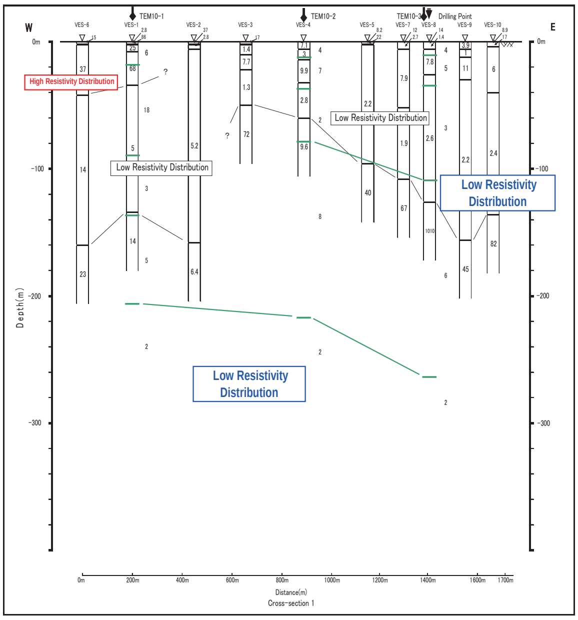


TEM Result of BH10



WS-2 ：TEMデータの逆解析

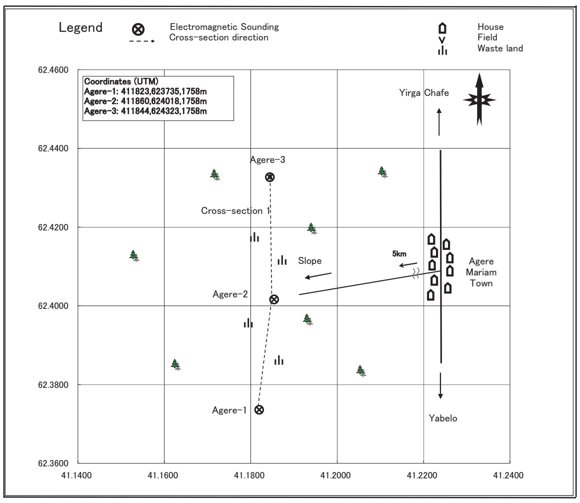
TEM Result of BH10



Estimated geology
1st-2nd:coarse sediments(gravel, sand)
3rd-5th:unconsolidated sediments, probably fine grained sediments or saturated with saline water
6th:volcanic rock(basalt)

Result
- **Generally a resistivity is low .**
- **The result of the VES and TEM almost corresponds.**
- **Aquifer top is the same as the depth of the low resistivity layer of a result of TEM.**

TEM Result of Agere Mariam



Location map （ Agere Mariam ）

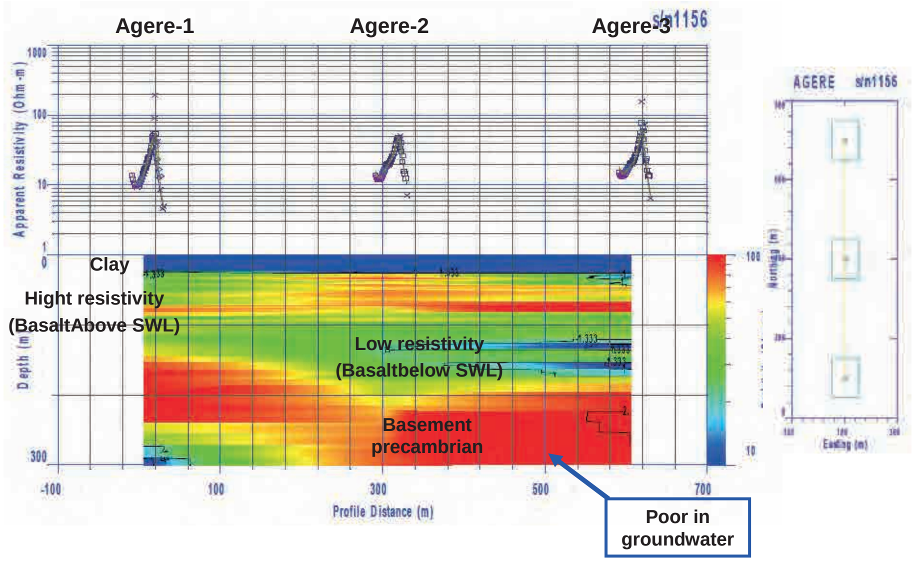
TEM : 3 points

Yirga Chafe

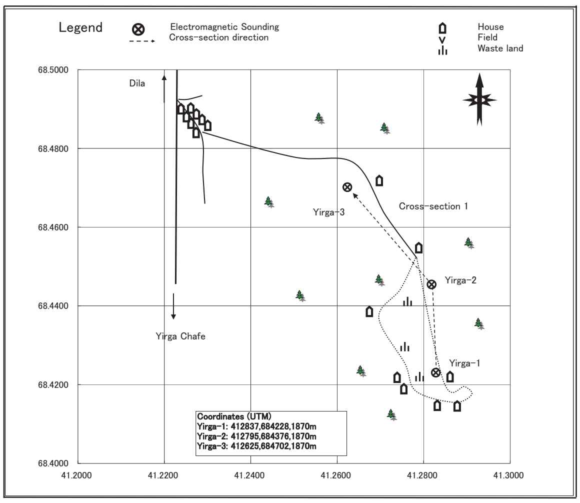
Survey site
Agere Mariam

WS-2 ：TEMデータの逆解析

TEM Result of Agere Mariam

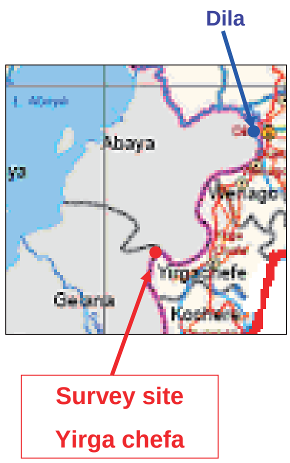


TEM Result of Yirga Chefe

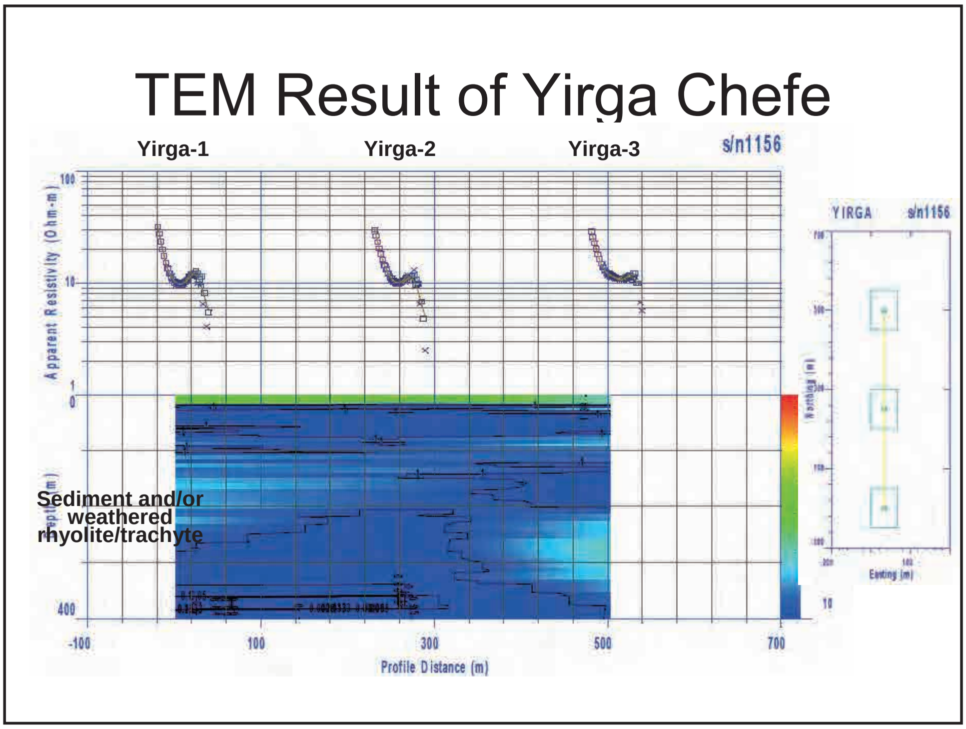


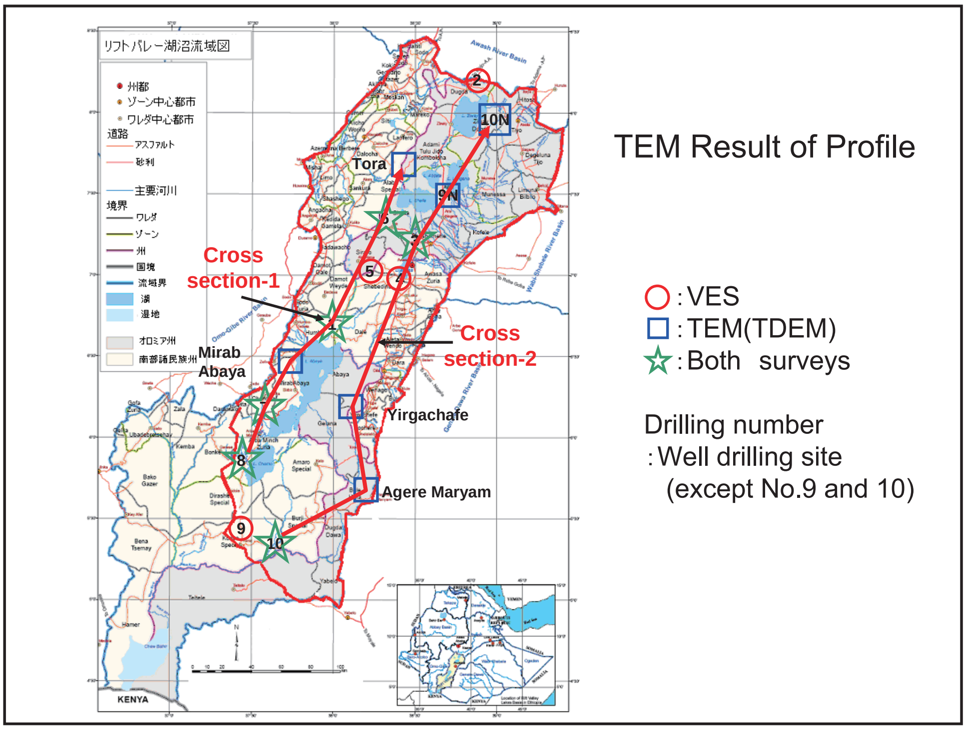
Location map（Yirga Chefe）

TEM : 3 points

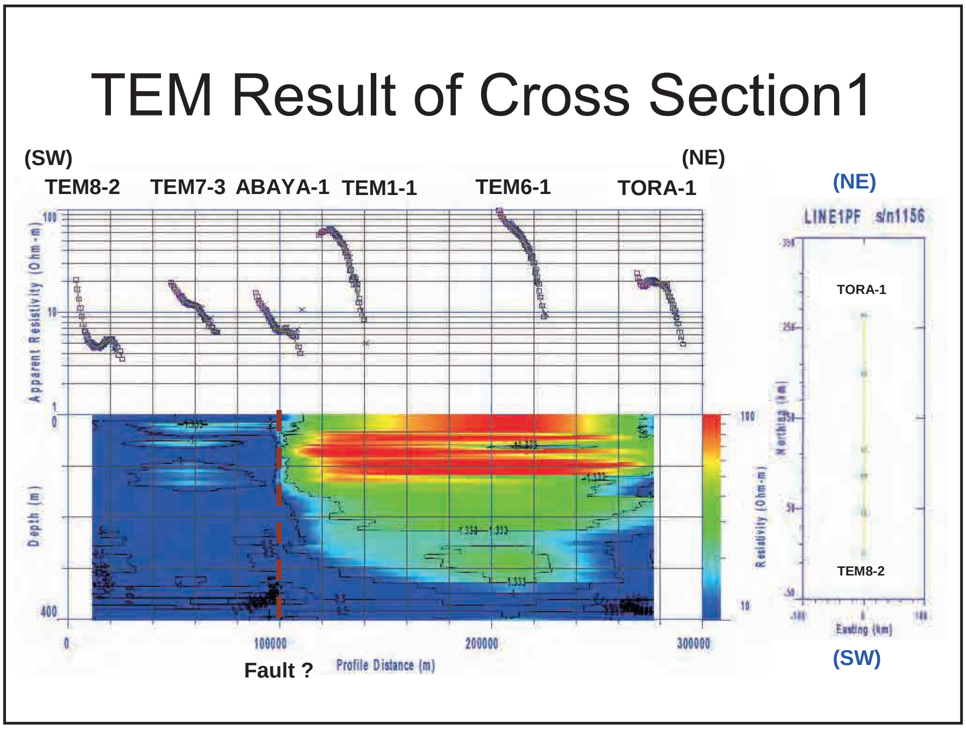


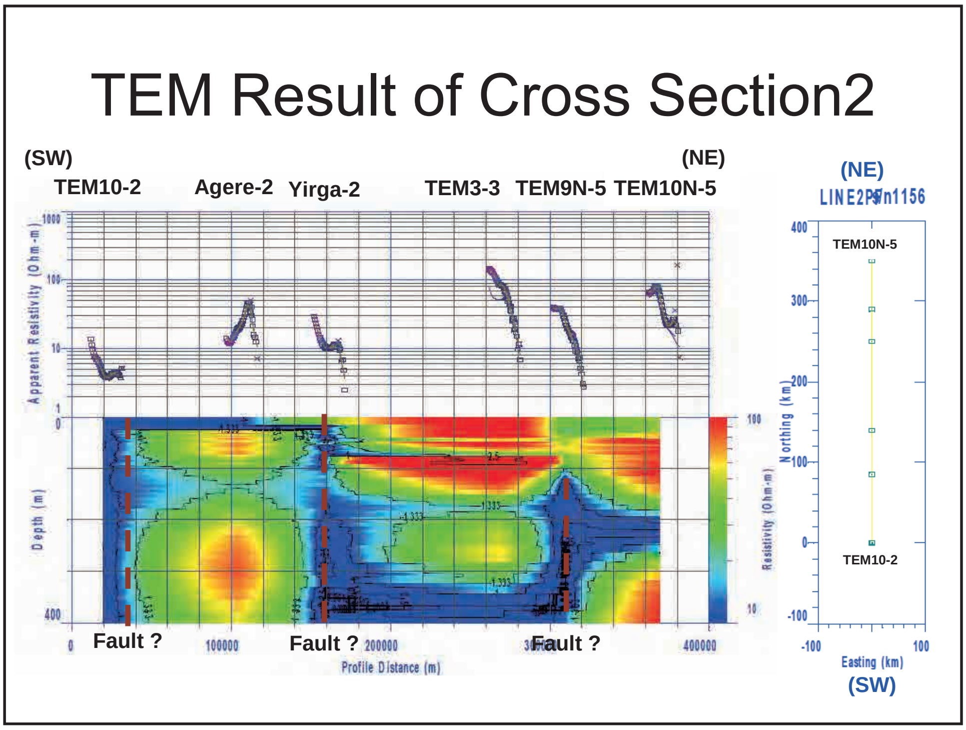
WS-2 ：TEMデータの逆解析





WS-2 ：TEMデータの逆解析





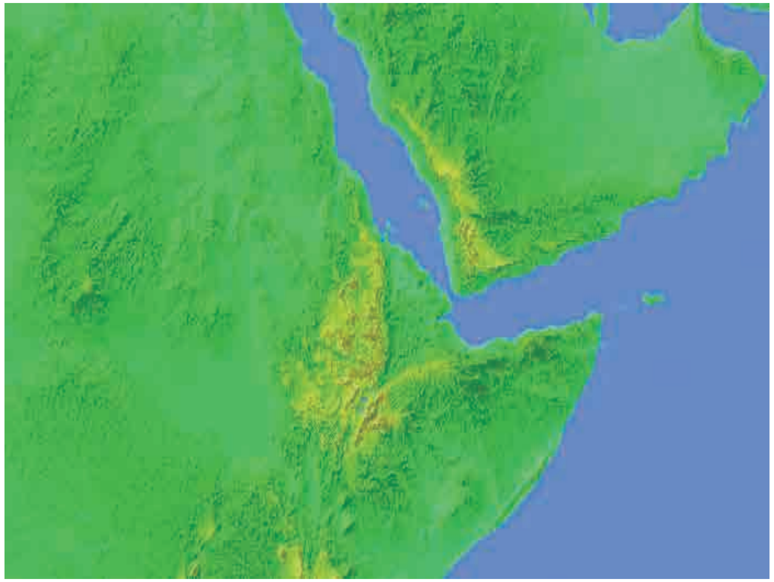
WS-2 ：TEMデータの逆解析

Thank you for your attention.

**The Study on
Groundwater Resources Assessment
in the Rift Valley Lakes Basin in Ethiopia**

WORKSHOP ON VOLCANIC GEOLOGY

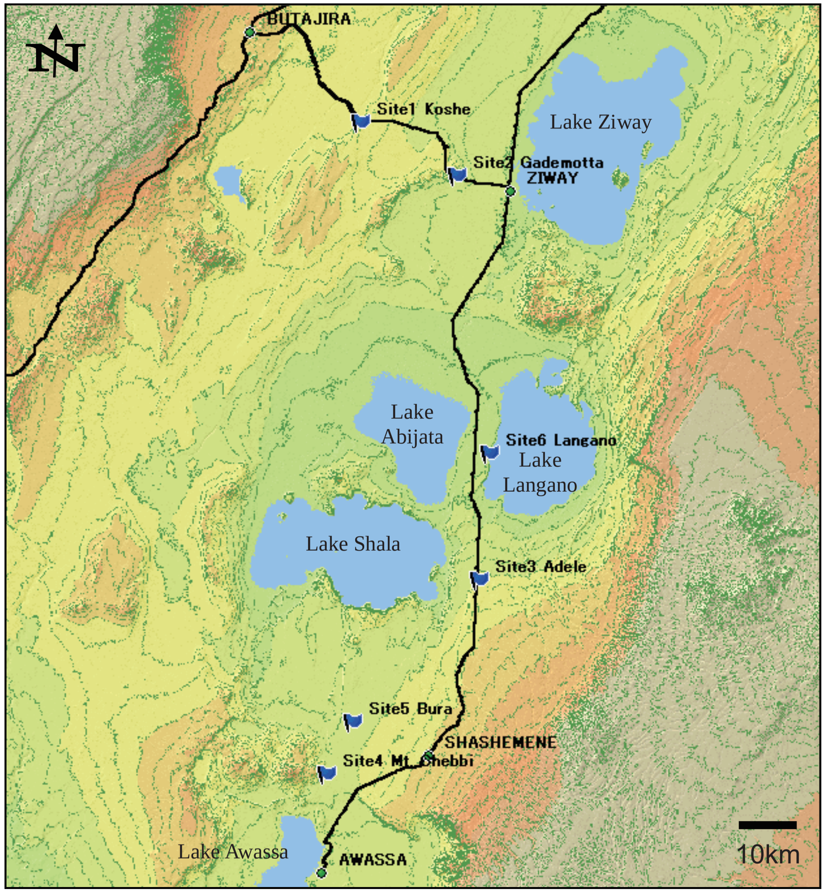
GUIDE BOOK



26 – 27th JANUARY 2011

JICA STUDY TEAM

MAP AND LOCATIONS



	Location	Longitude and Latitude (WGS84)	
1	Koshe	$8^0$00’55.3”N	$38^0$31’32.8”E
2	Gademotta	$7^0$56’50.5”N	$38^0$38’58.9”E
3	Adele	$7^0$25’49.2”N	$38^0$40’37.5”E
4	Mt.Chebbi	$7^0$10’52.5”N	$38^0$28’56.5”E
5	Bura	$7^0$14’52.1”N	$38^0$30’55.5”E
6	Langano	$7^0$35’32.5”N	$38^0$41’27.5”E

SCHEDULE

1st day :26th January 2011 (Wednesday)		Page
8:00	Rendez- vous	
8:00 – 11:00	Move to Koshe	
11:00 - 11:30	**Site 1 :Koshe (Koshe highly welded-tuff)**	**1**
12:00 – 12:45	**Site 2 :Gademotta (Gademotta Rhyolite)**	**3**
13: 00 – 14:00	Lunch in Ziway	
14:00 – 15:00	Move to Adele	
15:00 – 15:30	**Site 3 :Adele (Kuyera highly welded-tuff)**	**7**
15:30 – 17:00	Move to Awassa	
17:00	Arrive at a Hotel in Awassa	
2nd day :27th January 2011 (Thursday)		Page
8:30	Check-out	
8:30 – 9:00	Move to Mt. Chebbi	
9:00 – 9:30	**Site 4 :Mt. Chebbi (Corbetti Volcanics)**	**11**
9:30 – 10:00	Move to Bura	
10:00 – 10:30	**Site 5 :Bura (Awara recent basalt)**	**13**
10:30 – 12:00	Move to Lake Langano	
12:00 – 13:00	Lunch at Sabena Resort, Lake Langano	
13:00 - 13:30	**Site 6 :Langano (Langano poorly welded pumiceous pyroclastics)**	**15**
13:30 – 16:30	Back to Addis Ababa	

TUTOR:

Mr. Toshiaki HOSODA, Volcanic geologist, JICA Study Team

Mr. Hisayuki UKISHIMA, Hydrogeologist, JICA Study Team

Site 1 : Koshe

WHAT TO SEE
- ✓ **Distribution of Welded Tuff**
- ✓ **Structure of Welded Tuff**

Distribution of Welded tuff

Koshe is located in the middle of Butajira and Ziway. Welded tuff is observed along the scarp of NE-SW fault in Koshe. Same type of welded tuff was found at the fault scarp in Tora, south of Koshe, and south of Gademotta hill, indicates this type of welded tuff is widely distributed in this area.

Structure of Welded Tuff

Generally, welded tuff has flattered obsidian structure (*fiamme*), which shows that welded tuff had very high temperature in deposition on the ground (Fig.1).

Welded tuff in Koshe is characterized by containing many non-original fragments such as basalt and rhyolite.

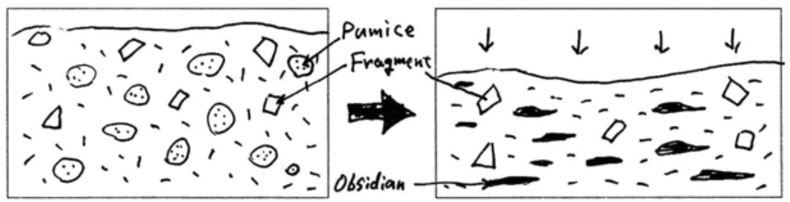


Fig.1: Schematic Diagram shows the formation of Obsidian Lens (*Fiamme*)

Fig.2: Outcrop of Welded Tuff in Koshe

Fig.3: Observation of Welded Tuff in Koshe. Non-original fragments are commonly found with flattered obsidian lens.

Site 2 : Gademotta

WHAT TO SEE
- ✓ **Topography of Gademotta Caldera**
- ✓ **Rhyolite Lava Flow and Obsidian**
- ✓ **Surge Deposit**

Topography

Gademotta hill is located in the west of Ziway. Gademotta hill is crescent rim of Gademotta Caldera. Opposite rim of caldera is not found recently.

GSE (1986) found a NW-SE structural gap from borehole data below Mt. Aluto, and the gap was considered as “the lost rim” of Gademotta Caldera (Fig.4). Thus, the opposite rim might be buried by evolution of Rift Valley Lakes Basin.

The shape of caldera was estimated 28 x 14 km ellipsoid and 300m deep, thus total volume of eruption is estimated around 94km^3

Rhyolite Lava flows and Obsidian

In the shoulder of Gademotta caldera, Rhyolite lava and obsidian are observed.

Rhyolite lava is intercalated by loose sediments at the Roadside and obsidian is observed at the rim of Rhyolite. Obsidian is considered as chilled margin of rhyolite at this site.

Fig.4: Topography of Gademotta Caldera

Rhyolite lava with flow structure and vertical columnar joint is observed at the quarry in the foot of caldera wall (Fig.5). Generally columnar joint is vertical to the isothermal gradient; therefore that rhyolite lava was cooled by the ground. K-Ar age of this rhyolite is 1.3 – 1.6 Ma (WoldeGabriel et al., 1990) and it indicates that Gademotta volcano was formed at that time.

Deposition of thick pyroclastics is related directly or indirectly

to calderas and most researchers believe that they were erupted from ring fractures concomitant from caldera collapse (R.V. Fisher and H.-U. Schminske 1984). Based on this point of view, Gademotta caldera might be one of the sources of welded tuffs observed in the northern part of Rift Valley Lakes Basin.


Fig.5: Observation of Rhyolite lava at the foot of Gademotta caldera. Vertical columnar joint shows that lava was cooled by the ground.

Surge Deposit

Base surge deposit is found at the shoulder of Gademotta Caldera. Base surge deposit is originated at the very initial period of eruption, and often forms characteristic lamination structure. (Fig. 6)

The direction of base surge is from SE to NW, may indicate that base surge is originated from Gademotta volcano, before the caldera collapse.

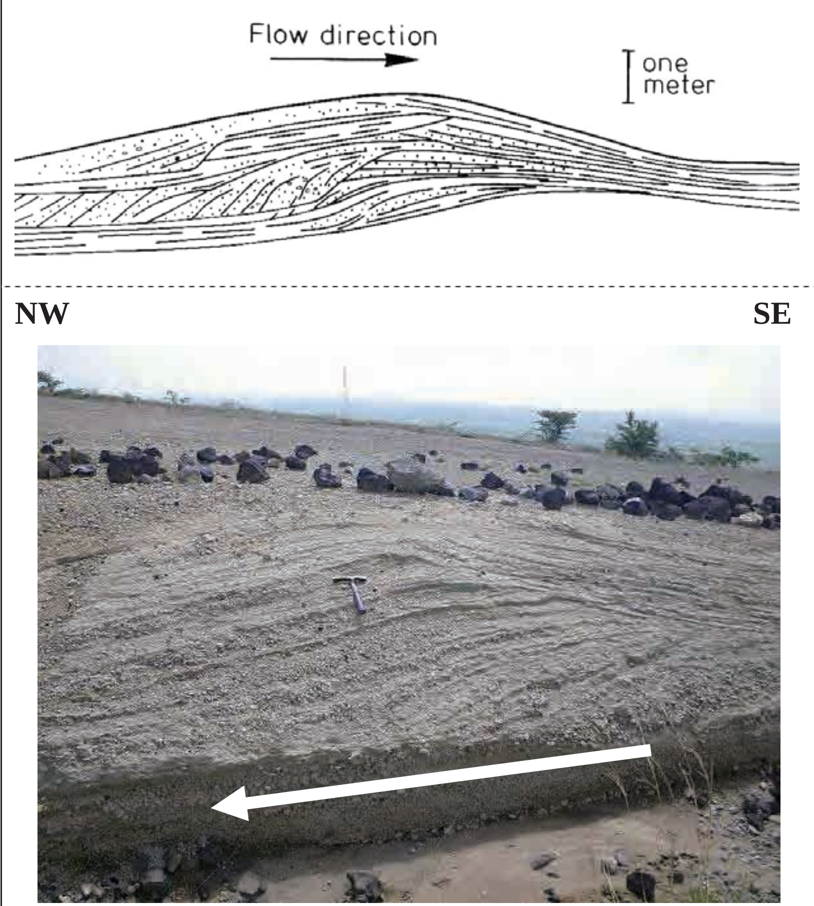


Fig.6: Schematic diagram of Chute-and-Pool structure in surge deposit (upper) and same structure observed at the roadside in the shoulder of Gademotta Caldera (lower). Flow direction is from SE to NW by the structure. (Upper figure is from “Pyroclastic Rocks” by R.V. Fisher and H.-U. Schminske 1984)

Site 3 : Adele

WHAT TO SEE
- ✓ **Structure of Welded Tuff**
- ✓ **Structure of Pumice Tuff**
- ✓ **Boundary between Welded Tuff and Pumice Tuff**

Topography

Adele is located at 7km east of Lake Shala. NNE-SSW active faults and ground cracks are observed at this Area. The outcrop is also located inside the big crack beside the road. Here, yellowish-gray pumice tuff overlies greenish-gray welded tuff .

Structure of Welded Tuff

Greenish-gray welded tuff is observed at the foot of the crack. Structure of welded tuff is different with that in Koshe; large flattered obsidians (*Fiamme*) are common in welded tuff and the length of obsidian is around 30cm maximum.

Structure of Pumice Tuff

Light yellowish-gray pumice tuff is observed at the shoulder of the crack. Many pumices and rock fragments are included in the tuff.

Boundary between Welded Tuff and Pumice Tuff

Boundary between welded tuff and pumice tuff are found at the bottom - middle of slope in the crack. The boundary is unclear. Generally, welded tuff is associated with non-welded part in the pyroclastic flow (Fig 3).

In the study, pumice tuff and welded tuff are classified and described as each formation. However, based on the structure of boundary, those formations have a possibility of single cooling unit.

Fig.7: Ground crack in Adele. The crack is around 20m deep, welded tuff and pumice tuff are observed at the cliff.

Fig.8: Welded tuff in Adele; flattered obsidians (*Fiamme*) are visible.

Fig.9: Boundary between welded tuff and pumice tuff. Boundary is unclear; which is considered that those formations might be single cooling unit.

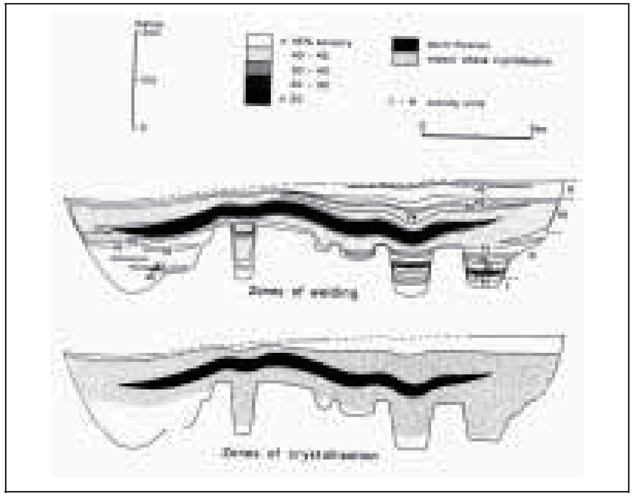


Fig.10: Diagram shows distribution of welded part in single cooling unit in Bandelier Tuff, New Mexico, USA.
(Source: www.nsm.buffalo.edu/courses/gly433/Welded.pdf)

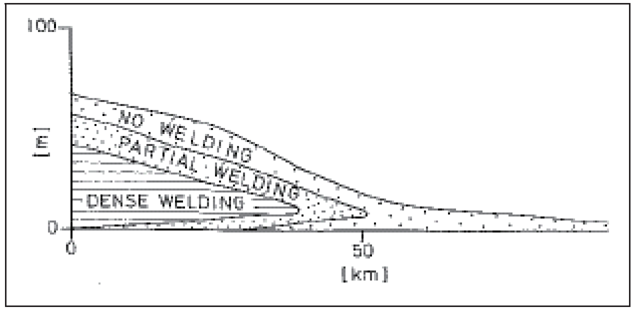


Fig.11: Idealized lateral and vertical configuration of welding zones in a single cooling unit. (from "Pyroclastic Rocks" by R.V. Fisher and H.-U. Schminske 1984, Fig 8-13 of Page 196)

Site 4 : Mt. Chebbi

WHAT TO SEE
- ✓ **Pumice Fall Deposit**
- ✓ **Obsidian Lava**
- ✓ **Boundary between Pumice fall and Obsidian Lava**

Topography

Mt. Chebbi is a volcano consisting Corbetti caldera, which is located at the northern part of Awassa. Corbetti caldera is consisted of two volcanoes; Mt. Chebbi and Mt. Urji. Mt. Urji is characterized by deposition of pumice fall and Mt. Chebbi is characterized by deposition of obsidian lava.

Pumice Fall Deposit

Pumice fall deposit is widely covered the surrounded area of Corbetti caldera, such as Awasa and Sheshemene town. At the site, pumice tuff is observed on the ground. The thickness of pumice fall deposit is around 2.0m at the roadside of Sheshemene - Awassa road, 1.0 m at Bura (Site 5).

Obsidian Lava

Obsidian cliff is observed at the site. Obsidian is observed at Gademotta caldera as chilled margin of rhyolite, however obsidian lava is observed at this outcrop. Obsidian lava overlies pumice fall deposit at the site. K-Ar age of this obsidian lava is 0.02 Ma, means that the eruption of obsidian was occurred in archeological period.

Fig.12: Outcrop of Obsidian lava (Left, cliff) and pumice fall (Right, on the ground).

Fig.13: Obsidian lava overlies pumice fall deposit.

Site 5 : Bura

WHAT TO SEE

- ✓ **Structure of Basaltic Scoria Cone**
- ✓ **Structure of Pumice Fall deposit**
- ✓ **Relationship between Basaltic Scoria Cone and Pumice Fall Deposit**

Topography

Bura is located at 12km west from Shashemene town. Some basaltic scoria cones are located in this area. Because basaltic scoria is so fresh that volcanic activities of basalt in this area seem to be relatively young.

Structure of Basaltic Scoria Cone

Basaltic scoria falls and small lava flows are stratified at the quarry site. Reddish-gray scoria fall deposit is weakly graded and thin basalt lava is intercalated. The stratification forms scoria cone.

Structure of Pumice Fall deposit

At the top of scoria fall deposits, 1m-thick yellowish-gray pumice fall deposit is observed. Pumice fall deposit is similar as that at Site 4, which might be originated from Mt. Urji. Based on this relationship, it is clear that basaltic scoria cone is performed before the eruption of Mt. Urji.

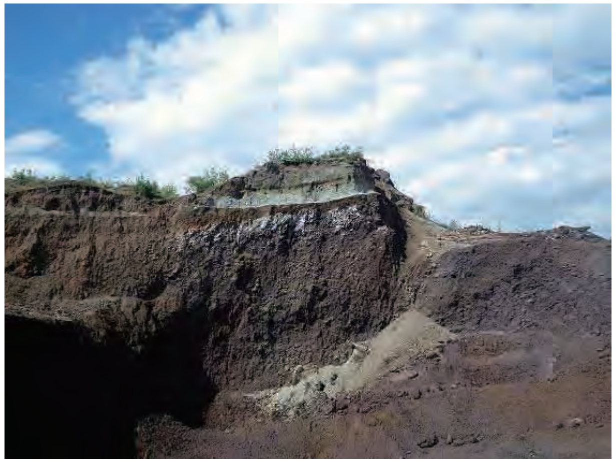


Fig.14: Basaltic scoria cone (Lower, reddish gray) and Pumice fall deposit (Top, yellowish gray).

Fig.15: Section of pumice fall deposit. The thickness is around 1.0m and slightly normal-graded.

Site 6 : Langano

WHAT TO SEE

- ✓ **Structure of Pumice Tuff**

Topography

The site is located at western shore of Lake Langano. The western shore of Lake Langano is characterized by the cliffs formed by succession of NNE-SSW faults. Yellowish gray pumice tuff is outcropped at 50m-height cliffs.

Structure of Pumice Tuff

Yellowish gray pumice tuff is massive and includes many pumices and non-original fragments. Matrix is composed of fine volcanic glass.

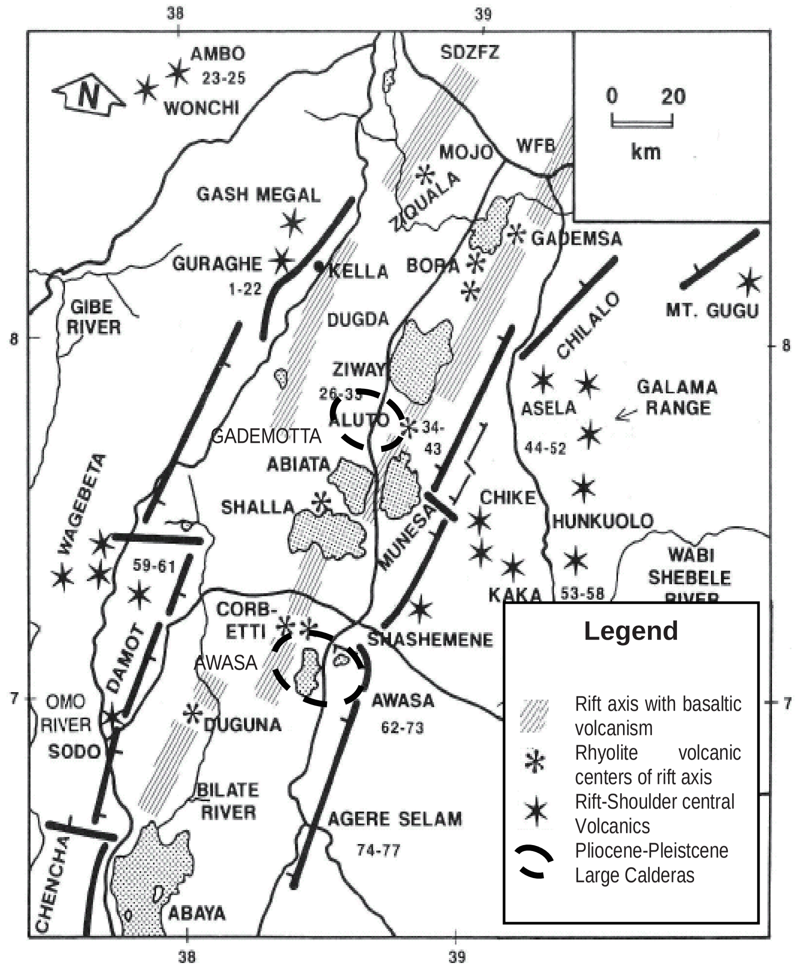
This pumice tuff is thickly distributed in this area and associated by the welded tuff at the bottom.

Mohr et al. (1980) and Le Turdu et al. (1999) considered that those pyroclastic units are originated by collapse of O'a caldera (Lake Shala), and the flow is distributed and thickly deposited at the eastern side of O'a caldera (See Appendix 2).

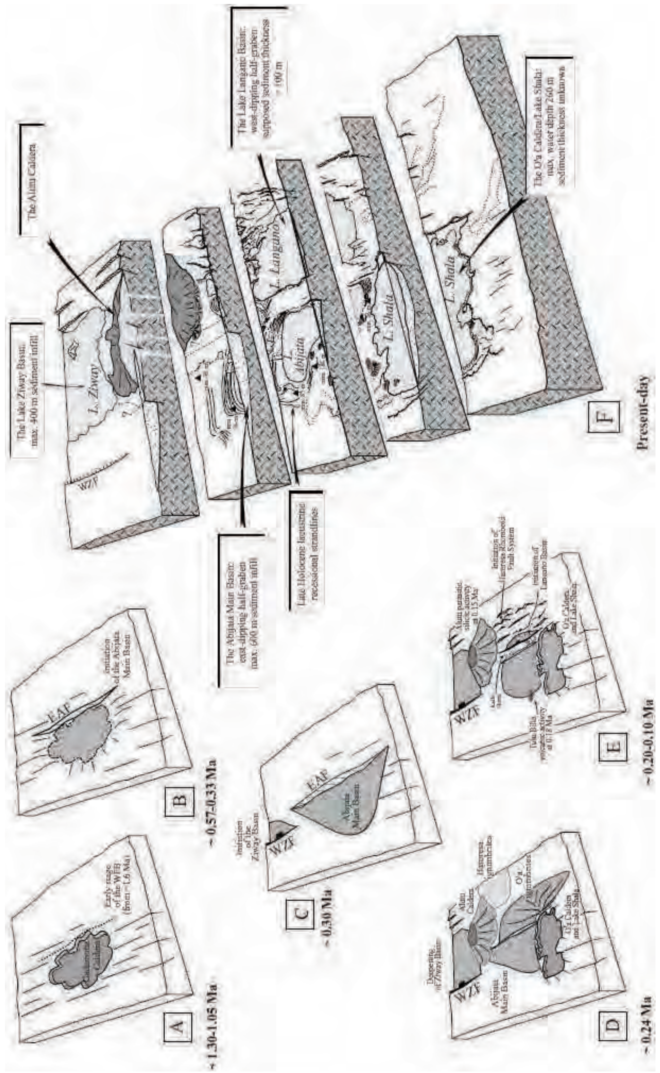
Fig.16: Cliff of Pumice tuff at the western shore of Lake Langano.

Fig.17: Pumice tuff observed at Lake Langano. Pumice tuff is massive and includes many pumices and non-original fragments. Matrix is composed of fine volcanic glass.

Appendix 1: Distribution of Volcanoes and Volcanic activity in the Rift Valley Lakes Basin (modified by WoldeGabliel et al., 1990)



Appendix 2: Schematic Block diagrams of the Evolution of the Ziway–Shala region from the Early Pleistocene to present-day (Le Turdu et al., 1999)



Appendix 3: Stratigraphy of northern part of Rift Valley Lakes Basin (in the Study)

Period/Epoch		Lake Ziway	Lake Langano, Abijata, Shala	Lake Awasa	Major lithology
Quaternary	Holocene	Alluvium	Alluvium	Alluvium	Fine sand - mud
		Bulbula lacustrine deposits	Bulbula lacustrine deposits	Shalo lacustrine deposits	Lake deposits such as gravel, sand and mud
		Mt. Aluto volcanics	Alge volcanics	Corbetti volcanics	Rhyolite lava flows, pumice falls, pumice flow deposits and Obsidian lava flows
		Butajira Recent Basalt	Awara Recent Basalt	Awasa Recent Basalt	Basalt lavas and reddish brown basaltic scoria
		Meki lacustrine deposits		Wondotika lacustrine deposits	Lake deposits such as poorly-sorted gravel, sand, pumice, tuff, and volcanic sand
	Pleistocene	Asela poorly welded pumiceous pyroclastics	Langano poorly welded pumiceous pyroclastics	Shashemene poorly welded pumiceous pyroclastics	Yellowish white rhyolitic pumice tuff
		Kulmusa highly Welded-Tuff	Kuyera highly Welded-Tuff	Mt. Kuwe highly Welded-Tuff	Rhyolitic to andesitic welded tuff
		Ketar river acidic volcano-sedimentary rocks	Lake Shala acidic volcano-sedimentary rocks	Yiega Alem acidic volcano-sedimentary rocks	Rhyolitic tuffs and pumice tuffs
		Gonde Strongly Green Welded-Tuff	Bilate river Strongly Green Welded-Tuff	Hantate Strongly Green Welded-Tuff	Rhyolitic to andesitic welded tuff
		Adami Tulu basaltic pyroclastics	Shala Senbete basaltic pyroclastics	Abaye ridge basaltic pyroclastics	Basaltic tuff breccias and lapilli tuffs
		Ogolche Basalt	Lepis Basalt	Yubo Basalt	Massive basalt lavas
		Lekansho Lake deposits			Lake deposits such as gravel, sand and mud
Neogene	Plio–Pleistocene	Gademotta rhyolite	Aje rhyolite	Wendo Genet Rhyolite	Rhyolite lava flows and rhyolitic tuffs
	Late Miocene to Pliocene	Bofa Basalt		Wijigra Rhyolite	Rhyolitic tuffs/ Basalt lavas and basaltic pyroclastics

All the maps are by SRTM-3 DEM at www.nasa.gov/ and processed by Kasimir3D: www.kasimir3d.com