社会開発調査部報告書

FEDERAL DEPARTMENT OF WATER RESOURCES
MINISTRY OF AGRICULTURE, WATER RESOURCES
AND RURAL DEVELOPMENT
FEDERAL REPUBLIC OF NIGERIA

# THE STUDY FOR GROUNDWATER DEVELOPMENT IN SOKOTO STATE

## VOLUME 3
## SUPPLEMENTARY REPORT 1

JULY, 1990

JAPAN INTERNATIONAL COOPERATION AGENCY



FEDERAL DEPARTMENT OF WATER RESOURCES
MINISTRY OF AGRICULTURE, WATER RESOURCES
AND RURAL DEVELOPMENT FEDERAL REPUBLIC OF NIGERIA
THE STUDY FOR GROUNDWATER DEVELOPMENT IN SOKOTO STATE
VOLUME 3 SUPPLEMENTARY REPORT 1
JULY, 1990 JICA

FEDERAL DEPARTMENT OF WATER RESOURCES
MINISTRY OF AGRICULTURE, WATER RESOURCES
AND RURAL DEVELOPMENT
FEDERAL REPUBLIC OF NIGERIA

# THE STUDY FOR GROUNDWATER DEVELOPMENT
# IN
# SOKOTO STATE

VOLUME 3
SUPPLEMENTARY REPORT 1

JULY, 1990

JAPAN INTERNATIONAL COOPERATION AGENCY

## TABLE OF CONTENTS

APPENDIX

1. LIST OF DATA COLLECTED
2. PREVIOUS INVESTIGATION AND RELEVANT GROUNDWATER
3. QUESTIONNAIRE SHEEL USED IN THE FIELD SURVEY
4. TECHNICAL TRANSFER PROGRAM
5. SURVEY EQUIPMENT / MATERIALS SUPPLIED BY JICA
6. SPECIFICATION FOR TEST DRILLING AND TEST WELL CONSTRUCTION
7. SPECIFICATION FOR TEST WELL CONSTRUCTION AND HAND PUMP INSTALLATION
8. SPECIFICATION FOR LEVELLING SURVEY
9. SPECIFICATION FOR MODEL WATER SUPPLY SYSTEM CONSTRUCTION
10. SCOPE OF WORK

# 1. SUMMARY OF SITE SURVEY

## 1-1 Preliminary Survey

The field surveys for the hydrological study and related water supply study were conducted by separate groups. While the hydrological study group did not always locate its observations with respect to the candidate villages, the group for hydrogeological and related water supply study visited the candidate villages one by one.
Forty-seven villages were visited from bases located at Sokoto, Argungu, Gusau, Zuru, Yauri and Koko. (Fig. 1-1)
The study group, after arriving in each candidate village, was divided into small parties for more effective engagement in the following activities:

a) Interview with the village head or village representative on the social conditions of the village, especially on water supply circumstances as reflected in the prepared questionnaire.

b) Observation of the existing water supply system and water sources, including measurement of water level in wells, checking of water quality (color, taste, temperature, electric conductivity, etc.), and sampling water for quality tests in the laboratory.

c) Topographic and geological mapping of the village and its surrounding area by pacing distances and using a clinometer to determine azimuth. Most of the villages have been mapped on a scale of 1/5,000 to represent the following items :

- clustered areas
- location of existing water sources for domestic use
- peculiar topographic features such as alluvial flats, terraces, ditches , or water channels, hills, cliffs, etc.
- type and facies of the rock where outcrops are found
- location of geophysical survey points
- direction

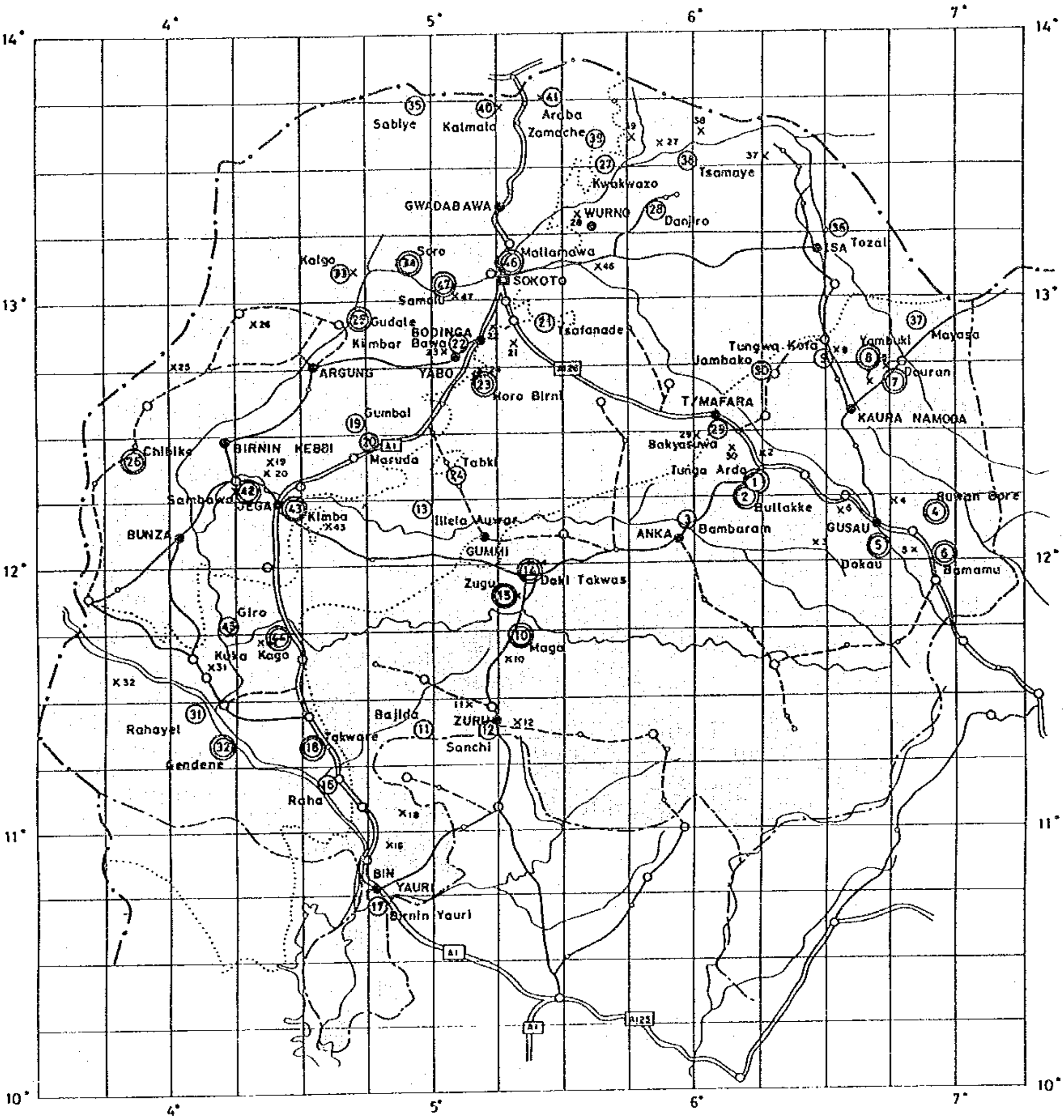



Fig. 1-1 Location Map of the Candidate Villages

Kms 50 0 50 100 150 Kms

③ : Preliminary Survey Points

⓵ : Detailed Survey Points

⓯ : Additional Experimental Point

d) Resistivity prospecting (ERP) in a method of vertical sounding using an McOHM type resistivity meter and four equally spaced electrodes. This survey was usually conducted by two parties with the cooperation of 5 to 8 local, casual laborers in each village.
The number of points measured was 2 to 4 in each village.

e) Resistivity mapping or resitivity sounding through the magnetotelluric method (MT method) by use of ELF-MT or PL-MT equipment. Two to five points were surveyed in each village with the cooperation of 2 to 4 local, casual laborers. For a comparison of the result with the above ERP, the survey points were located mostly to correspond with those of the ERP.

The results of preliminary survey are summarized in Table 1-1.

Table 1-1 Summary of Findings in Candidate Villages (1/8)

| No. | Village Name / Local Government | Population, Village Type (Clustering) | Access-ibility | Remarks on Economic, Social or Health Environment | Existing Water Source of Demestic Use | | Natural Condition for Groundwater Development | | | | Suitable Water Supply System | Grand-water potential | D/S Detailed Survey |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Type, Number of Water Soure | Quantity, Qualily and Major Probem | Hydrogeological Feature (Type, depth of formation or aquifer, Estimated yield) | Free Water Level m. B. G. S | Electric Conduc-tivity (μ /cm) | Topgoraphic Characteristics | | | |
| 1 | Tunga Ardo / Anka | • 30,000<br>• Scattererd (12 settlem-ents) | Good | • Guinea worm | • 1 deep dug well<br>• River<br>• Ponds | • Well is far from settlement<br>• Not enough through year | • Basement (Sch)<br>• weathered / fractured schist | 14.7 | 280 | Gentle hill | Semi-urban type or rural type | Generally poor (High in partial weathered zone) | D/S |
| 2 | Bullakke / Anka | • 10,500<br>• Scattererd | Good | — | • 1 hamd-pump | • Not enough (only one hand-pump in the scattered village) | • Basement(Gr)<br>• Fadama/ weathered granite | — | 660 | Rock hill | Hand-pumps or Rural system1 | Generally poor | D/S |
| 3 | Bambaram / Anka | • 10,000<br>• Scattered<br>• Each settlement is very small | Excel-lent | — | • Limited to river water | • Not enough through year<br>• Far (2km) from Settlement | • Basement | — | — | Generally flat | Hand-pumps | Poor | — |
| 4 | Ruwan Bore / Gusau | • 11,500<br>• Two concentrated settlements | Fairlly good | • Guinea worm | • 1 deep dug well<br>• stream | • Muddiness | • Basement<br>• Partially weathered to deep (more than 100m) | 13.7 | 700 | Close to river | Semi-urban type or Rural type system | Generally poor (High in partial weather-ed zone) | D/S |
| 5 | Dokou / Gusau | • 10,000<br>• Concentrat-ed (about 5ha) | Poor | • Guinea worm | • A number of private deep wells<br>• stream | • Not enough through year<br>• Salty (well), (high E/C) | • Basement (Gn)<br>• Deep weathering (more than 200m) or factured zone along tectonic line | 12.4 | 12.4 | • Generally flat<br>• Near from a stream | Semi-urban type system | High in deep weather ed zone | D/S |
| 6 | Bamamu / Gusau | • 10,000<br>• Scattererd (7 settle-ments) | Poor | • Semi-urban | • Small streams and ponds | • Not enough, no water in dry season<br>• Guinea worm | • Basement (Gr)<br>• Partially covered with recent river deposit | — | — | • Generally flat<br>• Small fadama | Hand-pump or Rural type system | Generally poor | D/S |

TABLE 1-1 Summary of Findings in Candidate Villages (2/8)

| No. | Village Name / Local Government | Population, Village Type (Clustering) | Access-ibility | Remarks on Economic, Social or Health Environment | Existing Water Source of Demestic Use: Type, Number of Water Soure | Existing Water Source of Demestic Use: Quantity, Qualily and Major Probem | Natural Condition for Groundwater Development: Hydrogeological Feature (Type, depth of formation or aquifer, Estimated yield) | Natural Condition for Groundwater Development: Free Water Level m. B. G. S | Natural Condition for Groundwater Development: Electric Conduc-tivity (μu/cm) | Natural Condition for Groundwater Development: Topgoraphic Characteristics | Suitable Water Supply System | Grand-water potential | D/S Detailed Survey |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 7 | Dauran / Kaura Namoda | • 23,500<br>• Concentrat-ed (about 20ha) | Excel-lent | • Semi-urban | • Stream<br>• 2 hand pumps (One is broken) | • Not enough through year | • Basement (Sch)<br>• Deep weathering to 40~70m | — | 890 | • Generally flat<br>• Near from a river | Semi-urban type | General-ly poor (High in partial weather ed zone) | D/S |
| 8 | Yambuki / Kaura Namoda | • 25,000<br>• Concentrat-ed (about 40ha) | Fairly good | • Guinea worm<br>• Large village ~Semi-urban | • 1 deep dug well<br>• Earth dam | • Not enough in dry season<br>• Salty (well) | • Basement(Gn, Peg)<br>• Deep weathering (50~70m) | 12.0 | 1,200 | Gentle slope along a river | Semi-urban type or Rural type system | General-ly poor (High in partial weather ed zone) | D/S |
| 9 | Tungwa Kofa / Kaura Namoda | • 1,500<br>• Scattered (3 settlements) | Good | — | • Stream | • Not enough through year<br>• Far (2km) from Settlement | • Basement<br>• Fresh rock is near to GS (15~40m) | — | — | Flat but near to small hills | S. A. R. D. A has a plan to drill hand pumps | General-ly poor | — |
| 10 | Maga / Zuru | • 4,000<br>• 2 concent-rated settlements | Excel-lent | • Semi-urban scale | • 1 hand pump<br>• 6 deep dug wells<br>• streams | • No water from wells in dry season | • Basement<br>• Irregular deep weathering (60~100m or more) | 7.8 | 95 ~ 300 | • Generally flat | Semi-urban type | Generally poor (High in partial weath-ered zone) | D/S |
| 11 | Bajida / Zuru | • 4,000<br>• Concentrat-ed | Very poor | — | • Limited to river water | • Not clean | • Basement (Gn)<br>• Shallow surface weathering (15 to 45m) | — | — | • A smooth hill, near from a river | Hand-pumps | Generally poor (High in partial weath-ered zone) | — |
| 12 | Sanchi / Zuru | • 15,000<br>• Not concen-trated, but not so scattered | Poor | • Located in moun-tains area | • 2 shallow dug wells | • Not enough through year | • Basement (Gf, Qz)<br>• Weathered gneiss | 4.0 | 190 | • Generally flat<br>• Sur-rounded by mountains | Hand-pumps are preferable (by request) | Generally poor (High in partial weath-ered zone) | — |

Table 1-1 Summary of Findings in Candidate Villages (3/8)

| No. | Village Name / Local Government | Population, Village Type (Clustering) | Access-ibility | Remarks on Economic, Social or Health Environment | Existing Water Source of Demestic Use: Type, Number of Water Soure | Existing Water Source of Demestic Use: Quantity, Qualily and Major Probem | Natural Condition for Groundwater Development: Hydrogeological Feature (Type, depth of formation or aquifer, Estimated yield) | Natural Condition for Groundwater Development: Free Water Level m. B. G. S | Natural Condition for Groundwater Development: Electric Conduc-tivity | Natural Condition for Groundwater Development: Topgoraphic Characteristics | Suitable Water Supply System | Grand-water potential | D/S Detailed Survey |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 13 | Illelar Auwal / Gummi | • 10,000<br>• Concentrat-ed (about 14.4ha) | Fairly good | — | • At leasts shallow wells | • Not enough in dry season | • Gwandu F. | 9.0 | (μs/cm)<br>280 ~ 285 | • General-ly flat, but slopes gently to swamp | Semi-urban type | Generally high | — |
| 14 | Daki Takwas / Gummi | • 20,000<br>• Concentrat-ed (about 35ha) | Excel-lent | • Semi-urban<br>• Located at a transport junction | • More than 10 deep dug wells | • Not enough in dry season | • Basement<br>• Partially covered with recent river deposit<br>• Very shallow sur-face weathering (5to 15m) | 9.0~17.8 | 52 ~ 210 | • Generally flat, near from fadama | Semi-urban type system | Generally poor | D/S |
| 15 | Zugu / Gummi | • 4,000<br>• Concentrat-ed (about 10ha) | Excel-lent | — | • 2 deep dug wells | • Not enough in dry season | • Basement<br>• Weathered Zone (5~10m³/d/m) | 10.9~11.2 | 330 ~ 470 | • A gentle slope, near from a river | Semi-urban type system | High in deep weathered zone | D/S* |
| 16 | Raha / Yauri | • 2,200<br>• Concentrat-ed (about 20ha) | Poor | — | • 2 shallow dug wells | • Not enough and poor quality | • Quaternary deposit<br>• –10~20m, (100m³/d/m) | 2.6 | 330 | • A gentle hill surrounde d by fadama | Rural type system or Hand-pumps | Generally high | — |
| 17 | Birnin Yauri / Yauri | • 22,000<br>• Concentrat-ed (about 20ha) | Excel-lent | • Semi-urban | • 7 deep dug wells | • Recharging rate is very low in every well<br>• Turbid through year | • Basement<br>• Weathered/frac-tured Zone | 7.0~15.6 | 510 ~ 600 | • Smooth hills devlded by small streams | Hand-pums | Very poor | — |
| 18 | Takware / Yauri | • 10,000<br>• Concentrat-ed (about 25ha) | Good | — | • More than 80 shallow dug wells (mostly dried up in dry season) | • Not enough in dry season | • Illo F.<br>(70m³/d/m) | 5.0 | 930 | • Generally flat, near from a river | Hand-pumps (are preferable by request) | Generally high (partially) | D/S |

* Additional experimental survey

Table 1-1 Summary of Findings in Candidate Villages (4/8)

| No. | Village Name / Local Government | Population, Village Type (Clustering) | Accessibility | Remarks on Economic, Social or Health Environment | Existing Water Source of Demestic Use: Type, Number of Water Soure | Existing Water Source of Demestic Use: Quantity, Qualily and Major Probem | Natural Condition for Groundwater Development: Hydrogeological Feature (Type, depth of formation or aquifer, Estimated yield) | Free Water Level m. B. G. S | Electric Conductivity (μu/cm) | Topgoraphic Characteristics | Suitable Water Supply System | Grand-water potential | D/S Detailed Survey |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 19 | Gumbai / Birnin kebbi | • 6,000 • Concentrated (about 8ha) | Good | – | • about 40 shallow dug wells • 2 hand pumps (under constraction) | • Enough water through year | • Gwandu F. • Alluvium (– 4~–10m, >100m³/d/m) | 3.8~6.15 | 510 ~ 570 | • Narrow valley plain • Fadama | • S. A. R. D. A. is construc ting hand pomps | Generally high | – |
| 20 | Maruda / Birnin kebbi | • 3,000 • Concentrated (about 10ha) | Poor | • Less demand for additional W/source | • about 60 shallow dug wells • 3 hand pumps (under constraction) | • Enough water through year | • Gwandu F. • Alluvium (– 4~–6m, >100m³/d/m) | 3.2~4.15 | 260 ~ 630 | • Narrow valley plain • Fadama | • S. A. R. D. A. is construc ting hand pumps | Generally high | – |
| 21 | Tsafanade / Bodinga | • 2,000 • Not Concentrated, but not so scattered | Good | • Very near from Sokoto | • 1 hand pump • 5 deep dug wells | • No water from dug wells in dry season | • Kalambaina F./ Rima G. (10m³/d/m) | 5.8 | 115 ~ 240 | • The edge of plateau | Rural type | Generally high | – |
| 22 | Kimbar Bawa / Bodinga | • 300 • Concentrated (about 1.5ha) | Poor | • Less demand for additional W/source | • 3 deep dug wells • pond | • Quality is good (well) | • Gwandu F./ Kalambaina F. (80m³/d/m) | 12.2~15.0 | 380 ~ 620 | • Gentle slope, near from river, pond | Hand-pumps | Generally high | – |
| 23 | Horo Birni / Yabo | • 8,000 • Concentrated (about 25ha) | Fairly good | • High demand for boreholes | • I deep dug well • about 100 shallow dug wells | • Not enough in dry season | • Kalambaina F. (40m³/d/m) | 45.5 | 300 | • Generally flat | Semi-urban type system | Generally high | D/S |
| 24 | Tabki / Yabo | • 200 • Concentrated (about 2ha) | Excellent | • Less demand for additional W/source | • I deep dug well a big pound | • Not enough in dry season | • Rimam F./ Gundumi F. (30)/(60m³/d/m) | 47.3 | 240 | • Generally flat, near from Fadama | Rural type | Generally poor | – |

Table 1-1 Summary of Findings in Candidate Villages (5/8)

| No. | Village Name / Local Government | Population, Village Type (Clustering) | Accessibility | Remarks on Economic, Social or Health Environment | Existing Water Source of Demestic Use: Type, Number of Water Soure | Existing Water Source of Demestic Use: Quantity, Qualily and Major Probem | Natural Condition for Groundwater Development: Hydrogeological Feature (Type, depth of formation or aquifer, Estimated yield) | Natural Condition for Groundwater Development: Free Water Level m. B. G. S | Natural Condition for Groundwater Development: Electric Conductivity (μu/cm) | Natural Condition for Groundwater Development: Topgographic Characteristics | Suitable Water Supply System | Grand-water potential | D/S Detailed Survey |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 25 | Gudale / Argungu | • 11,000<br>• Concentrated (about 10ha) | Good | — | • 4 deep dug well | • Quality is poor, but bearable<br>• Not enough in dry season | • Gwandu F.<br>• Alluvium/ Gwandu F.<br>(30m³/d/m) | 6.4~9.7 | 160 ~ 710 | • Generally flat, near from big Fadama of Niger river | Semi-urban type system | Generally high | D/S |
| 26 | Chibike / Argungu | • 5,000<br>• Scattered (3 settlement) | Good | • High demand for further water suplly | • 1 deep dug well only | • Quality is poor, but bearable<br>• Not enough through year | • Gwandu F.<br>(47m³/d/m) | 36.0 | 46 | • Generally flat along a stream | Semi-urban type or Rural type system | Generally high | D/S |
| 27 | Kwakwazo / Wurno | • 4,000<br>• Concentrated (about 15ha) | Poor | — | • 4 deep dug wells<br>• pond (for animals) | • Quality is poor, but bearable<br>• Not enough through year | • Rima G.<br>• Alluvium/ Rima G.<br>(10m³/d/m) | 7.8~9.2 | 480 ~ 2400 | • Fadama of River Rima | Semi-urban type system or Hand-pumps | Generally high | — |
| 28 | Danjiro / Wurno | • 2,000<br>• Concentrated (about 2ha) | Poor no access in heavy rain | — | • 2 hand pumps<br>• 1 deep dug well | • High iron content<br>• Not enough in dry season | • Rima G.<br>(2~10m³/d/m) | 20.3 | 1,650 | • Generally flat<br>• Near from small Fadamas | Rural type system or Hand-pumps | Generally high | — |
| 29 | Bakyasuwa / Talata Mafara | • 1,000 (~3,000)<br>• Scattered (more than 3 settlements) | Good | • Located near the Gusau Road | • 1 hand pump | • Not enough through year | • Basement (Gn~Gr)<br>• Monotonous surface weathering (30~40m)<br>• Partial deep weathering (fissure) (2~10m³/d/m) | — | 99 | • Generally flat near from a stream | Rural type system or Hand-pumps | Generally poor | — |
| 30 | Jambako / Talata Mafara | • 22,000<br>• Concentrated (about 50ha) | Poor | — | • 1 deep dug well<br>• Stream | • One well is not enough for the so many people | • Bsement (Gr)<br>• Weathered/fractured granite<br>(5~10m³/d/m) | 12.7 | 520 | • Generally flat, along a river | Hand-pumps (many) | Generally poor | — |

Table 1-1 Summary of Findings in Candidate Villages (6/8)

| No. | Village Name / Local Government | Population, Village Type (Clustering) | Accessibility | Remarks on Economic, Social or Health Environment | Existing Water Source of Domestic Use: Type, Number of Water Soure | Existing Water Source of Domestic Use: Quantity, Qualily and Major Probem | Natural Condition for Groundwater Development: Hydrogeological Feature (Type, depth of formation or aquifer, Estimated yield) | Natural Condition for Groundwater Development: Free Water Level m. B. G. S | Natural Condition for Groundwater Development: Electric Conductivity | Natural Condition for Groundwater Development: Topgoraphic Characteristics | Suitable Water Supply System | Grand-water potential | D/S Detailed Survey |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 31 | Rahayel / Bagudo | • 1,500<br>• Concentrated (about 4ha) | Poor | • Located on the west side of the River Niger | • At least 4 shallow dug wells | • Not enough in dry season | • Illo F. | 13.7 | (μ /cm) 330 | • Generally flat, with dotted hills | Rural type system | Generally high | — |
| 32 | Gendene / Bagudo | • 3,100 (~11,000)<br>• Concentrated (about 4ha)<br>• Scattered village also | Good | • Located on the west side of the River Niger | • 3 shallow dug wells<br>• River (Niger) | • Not enough in dry season | • Illo F.<br>(20~100m³/d/m) | 4.0~7.8 | – | • Gentle hill, near from the River Niger | Semi-urban type or Rural type system | Generally high | D/S |
| 33 | Kalgo / Silame | • 3,000<br>• Concentrated (about 9ha) | Poor | • In rainy season, access roads are cut off | • 6 deep dug wells | • Water quality is poor but bearable.<br>• Quantity is barely satisfactory | • Gwandu F.<br>(20m³/d/m) | 19.5~27.7 | 120 ~ 470 | • Gentle soomth hill, near from Fadama of River Rima | Hand-pumps | Generally (partially) | — |
| 34 | Soro / Silame | • 4,500<br>• Concentrated (about 3ha) | Good | – | • 5 deep dug wells | • Water quality is poor but bearable<br>• Not enough Through year | • Gwandu F.<br>(33m³/d/m) | 7.0~9.0 | 120 ~ 210 | • Flat, and near from a river | Rural type system | Generally high | D/S |
| 35 | Sabiye / Silame | • 3,000<br>• Concentrated (about 6ha) | Poor | • Located near the border of Republic of Niger | • 1 shallow day well | • Water quality is poor | • Gwandu F. | 18.5 | 95 | • Generally sloping to the NW | Hand-pumps | Generally (partially) | — |
| 36 | Tozai / Isa | • 5,000<br>• Concentrated (about 28ha) | Poor | • In rain Season, access roads are cut off | • At least 3 shallow day wells | • Water quality is poor, but bearable | • Gwandu F. | 9.6 | 500 | • Generally flat | Hand-pumps | Generally high | — |

Table 1-1 Summary of Findings in Candidate Villages (7/8)

| No. | Village Name / Local Government | Population, Village Type (Clustering) | Accessibility | Remarks on Economic, Social or Health Environment | Existing Water Source of Demestic Use: Type, Number of Water Soure | Existing Water Source of Demestic Use: Quantity, Qualily and Major Probem | Natural Condition for Groundwater Development: Hydrogeological Feature (Type, depth of formation or aquifer, Estimated yield) | Natural Condition for Groundwater Development: Free Water Level m. B. G. S | Natural Condition for Groundwater Development: Electric Conductivity | Natural Condition for Groundwater Development: Topgoraphic Charcteristics | Suitable Water Supply System | Grand-water potential | D/S Detailed Survey |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 37 | Mayasa / Isa | • 10,000<br>• concentrated (about 56ha) | Good | • Semi-urban<br>• In rainy season, access roads are cut off | • 3 hand pumps<br>• 1 small earth dam | • Water quality is poor but bearable | • Basement | — | (μ /cm) 650 ~ 700 | • Generally flat | • Semi-urban type | Generally poor | — |
| 38 | Tsamaye / Isa | • 5,500<br>• Made up of 18 concentrated settlements | Faily good | • Resettled by constructi on of Goronyo Dam | • 2 boreholes with water tanks<br>• 3 deep dug wells<br>• 2 hand pumps (not moving) | • Pool maintenance for power pumps and hand pumps<br>• Quantity is rather good | • Rima G. /Gundumi F. | 34.0~39.8 | Poor but bear-able (185~230) | • Generally flat, near from Gronyo Dam | • Existing system can be used if rehabilit ated | Generally poor | — |
| 39 | Zamache / wurno | • 1,500<br>• Concentrat-ed (about 5ha) | Very poor | — | • 6 deep dug wells | • Water quality is poor but bearable<br>• Not enough through year | • Kalambaina F./ Rima G. | 7.7~10.0 | Poor but bear-able (515~660) | • Plateau, near from es-carpments | • Hand-pumps | Generally poor | — |
| 40 | Kalmalo / Gwadabawa | • 50,000<br>• Concentrat-ed (about 40ha) | Good | • Semi-urban<br>• Guinea worm (a few) | • Water distribu-tion (not moving)<br>• 10 deep dug wells | • Poor maintenance for the system<br>• Water is salty and not enough | • Gwandu F./ Kalambaina F. | 7.7~8.2 | 1,700 ~ 2,750 | • Generally flat, facing to Kalmalo Lake | • Existing system is apropreate if rehabilit ated | Generally high | — |
| 41 | Araba / Gwadabawa | • 3,200<br>• Concentrat-ed (about 20ha) | Fairly good | • New to the border of Niger | • Water distribution (not moving)<br>• 39 shallow/deep dug wells | • Maintenance for existing borehole<br>• Water is not so poor but turbid | • Kalambaina F. | 6.4~10.5 | 500 ~ 520 | • Generally flat | • Existing system is apropria te if rehabili-tated | Generally (partially high) | — |
| 42 | Sambawa / Jega | • 8,000<br>• Concentrate-d (about 14ha) | Good | • Located along Zamfara River | • 2deep dug wells<br>• River (Zamfara) | • Salty but bearable (well)<br>• Enough water (river) at not clean | • Gwandu F. | 8.0 | 295 ~ 440 | • Generally flat, facing to the Zamfara river | • Semi-urban type system | Generally high (partially) | — |

Table 1-1 Summary of Findings in Candidate Villages (8/8)

| No. | Village Name / Local Government | Population, Village Type (Clustering) | Accessibility | Remarks on Economic, Social or Health Environment | Existing Water Source of Domestic Use: Type, Number of Water Soure | Existing Water Source of Domestic Use: Quantity, Qualily and Major Probom | Natural Condition for Groundwater Development: Hydrogeological Feature (Type, depth of formation or aquifer, Estimated yield) | Natural Condition for Groundwater Development: Free Water Level m. B. G. S | Natural Condition for Groundwater Development: Electric Conductivity | Natural Condition for Groundwater Development: Topgoraphic Characteristics | Suitable Water Supply System | Grand-water potential | D/S Detailed Survey |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | (μ /cm) | | | | |
| 43 | Kimba / Jega | • 6,200<br>• Concentrated (about 13ha) | Good | • Located along Zamfara River | • 3 deep dug wells<br>• (River Zamfara) | • Water quality is poor but bearable (well)<br>• Quantity is enough, but not clean (river) | • Gwandu F./ Kalambaina F. (93m3/d/m) | 8.6~11.4 | 140 ~ 680 | • Generally flat, facing to the Zamfara river | Semi-urban type system | Generally high | D/S |
| 44 | Kuka Kogo / Jega | • 3,500<br>• Concentrated (about 5ha) | Good | • Gastro-enteritis and dysentery are prevalent | • Limited to river water, of Gulbinka | • Very poor quality with sanitary problem | • Illo F. (50~80m3/d/m) | — | — | • Gentle slope, facing to Gulbinka | Semi-urban type or Rural type system | Generally high | D/S |
| 45 | Giro / Bunza | • 7,300<br>• Concentrated (about 10ha) | Poor | • Located along Rima River | • 6 deep dug wells<br>• 2 hand pumps (not moving) | • Quantity is barely satisfactory (well) | • Illo F. (50~100m3/d/m) | 20 | — | • Generally flat, between fadama and hill | Semi-urban type system (under preparation) | Generally high | — |
| 46 | Mallamawa / Sokoto | • 10,000<br>• Concentrated (about 5ha) | Good | • Near the fadama of the River Rima | • Many shallow wells in the fadama<br>• 1 hand pump (broken) | • Wells are far (850m) from the settlement | • Kalambaina F./ Rima G. | — | — | • Gentle slope bordered by escarpments<br>• Near from fadama | Semi-urban type system | Generally poor | D/S |
| 47 | Samalu / Sokoto | • 4,500<br>• Concentrated (about 5ha) | Good | | • 2 deep dug wells | • Not enough through year | • Gwandu F. (75m3/d/m) | 23.0~26.0 | 59 ~ 81 | • Generally Flat | Semi-urban type or Rural type system | Generally high | — |

## 1-2 Detailed Survey

A field survey for hydrogeological study was conducted in detail in the 21 selected candidate villages and their surroundings, based on the results of preliminary hydrogeological investigation and additional aerial photography interpretation. A detailed site survey was simultaneously conducted in order to properly locate test drilling sites. (Fig. 1-1)

This hydrogeological reconnaissance was carried out parallel to geophysical prospecting in each candidate village. Based on the results of reconnaissance and the geophysical prospecting, a comprehensive hydrogeological analysis was simultaneously conducted in order to evaluate the groundwater potential to determine test drilling points and to prepare for the planning of a water supply system.

The results of this work are summarized in Table 1-2 and are presented in detail in the outline maps of the detailed hydrogeological survey in this volume.

Table 1-2 Result of Detailed Survey (1/3)

| | Village Name Population (Local Gov.) | Groundwater Potential: Hydrogeological Features | Groundwater Potential: Result of Geophysical Prospecting | Groundwater Potential: Expected W/Quality | Social and Health Environment | Willingness and Payability for Operation and Maintenance | Access-ibility | Result of Test Drilling and Well Discharge | Recommendable Water Supply System |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Tunga Ardo 30,000 (Anka) | ·Weathered and fractured schist with granite dykes ·S/C : 9m$^3$/d/m (from existing boreholes) | ·Partial deep weathering (more than 60m ) in the southeast of settlement ·Higher G/water potential is expected along granite dyke | ·Good ·E/C 280 (μυ/ cm) | ·Scattered village with 12 settlements ·Guinea worm disease ·Urgent necessity for borehole water | Strong (100% of Fami. N1~5/M/F) | Good | T/D (80m) 17ℓ/min by air lift | Numbers of hand-pump wells with 40 to 50 m depths |
| 2 | Bullake 10,500 (Anka) | ·Thin Alluvial deposits and weathered granite with pegmatite veins ·S/C : 3m$^3$/d/m | ·Basin shaped deep weathering (45~90m) in N-S direction controled by structural lineament | ·Good ·E/C 660 | ·Scattered village ·Shortage of water in dry season | Normal (100% of Fami. N1~3/M/F) | Good | — | 6 to 8 hand-pump wells with depth of 40 to 60 m at the places of basin wide deep weathering |
| 4 | Ruwan Bore 11,500 (Gusau) | ·Weathered and fractured schist with quartzite veins ·S/C : 0.7~32m$^3$/d/m | ·N-S basin shaped deep weathering (70~170m) controled by structural lineament ·Higher G/water potential along quartzite veins | ·Good ·E/C 700 | ·Guinea worm disease ·Urgent necessity for borehole water | Normal (More than 50% of Fami. N2~3/M/F) | Fairly good | T/D(84m) 49ℓ/min T/W(90m) 84~168ℓ/min by air lift | Small capacity power pump elevated tank and gravity destribution system with 4 to 5 communal fauset |
| 5 | Dokau 10,000 (Gusau) | ·Weathered and fractured schist ·Situated in wide fractured zone with evident N-S lineament ·S/C : 0.2~6m$^3$/d/m (Outside of fractured zone) | ·Very deep weathering in whole area with fracturing and fault clay ·G/water potential may generally be high, but w/level might be different by place to place due to irregular fracturing facies | ·Salty ·E/C 1,200 | ·Concentrated and semi-urban style village ·Urgent requirement for borehole water ·Guinea worm disease | Strong (100% of Fami. N1~5/M/F) | Poor | — | Borehole with power pump, elevated tank near the center of village with gravity distribution system |
| 6 | Bamamu 10,000 (Gusau) | ·Weathered and fractured granite covered with thin Alluvial deposits. ·S/C : 1~14m$^3$/d/m | ·Valley shaped partial deep weathering (45~60m) in N-S direction controled by structural lineament | — | ·Scattered village with 7 settlements ·Guinea worm disease ·Urgent necessity for borehole water | Strong (100% of Fami. N1~5/M/F) | Poor | — | 6 to 7 hand pump wells with depth of 40 to 50 m at the places of basin wide deep weathring |
| 7 | Dauran 23,500 (Kaura Namoda) | ·Weathered schist with fractured zone ·S/C : 1~200m$^3$/d/m | ·Valley shaped partial deep weathering (45~90m) in directions of NW and NE | ·Good ·E/C 890 | ·Semi-urban style village ·Serious shortage of water through the year | Normal (More than 70% of Fami. N1~3/M/F) | Excell-ent | T/W(84m) 120~210ℓ/min by air lift | 2 wells with motor pump with semi-urban type water supply system (Gravity) |
| 8 | Yambuki 25,000 (Kaura Namoda) | ·Weathered gneiss and granite with fractured zone ·S/C : 2~200m$^3$/d/m | ·Partial deep weathering (45~160m) in NS, NW and NE directions controled by structural lineament | ·A little salty ·E/C 1,200± | ·Semi-urban style village ·Seriously sufferd by Guinea worm disease ·Shortage domestic water has begun due to collapse of the dam by 1988'2 flood. | Strong (100% of Fami. N1~5/M/F) | Fairly good | T/D(80m) 69ℓ/min T/W(102m) 80ℓ/min by air lift | 2 wells with small capacity motor pump with semi-urban type water supply system (Gravity) |

S/C : Range of specific capacity of existing wells nearby or surroundings of concerned area
N : Naira
E/C : Electric Conductivity in μυ/cm
/M/F : Per Month Per Family

Table 1-2 Result of Detailed Survey (2/3)

| No. | Village Name Population (Local Gov.) | Groundwater Potential: Hydrogeological Features | Groundwater Potential: Result of Geophysical Prospecting | Groundwater Potential: Expected W/Quality | Social and Health Environment | Willingness and Payability for Operation and Maintenance | Access-ibility | Result of Test Drilling and Well Discharge | Recommendable Water Supply System |
|---|---|---|---|---|---|---|---|---|---|
| 10 | Maga 4,000 (Zuru) | ·Weathered and fractured schist and meta-sediments with quartzite veins ·S/C : 0.8m³/d/m | ·Basin shaped deep weathering (70~170m) in a direction of NE-SW controled by structural lineament | ·Good ·E/C 95~300 | ·Serious shortage of domestic water during dry season | Normal (100% of Fami. N 1/M/F) | Excel-lent | T/D(84m) 5~20ℓ/min T/W(138m) 120~200ℓ/min by air lift | Gravity distribu-tion system, with a water source of drilled Test Well. |
| 14 | Daki Takwas 20,000 (Gummi) | ·Weathered schist and meta-sediments ·S/C : unknown due to no nearby borehole | ·Generally monotonous and shallow surface weathering with a depth ranging from 20 to 30m. ·Comparatively poor G/water potential | ·Good ·E/C 52~300 | ·Concentrated and semi-urban style village ·Serious shortage of domestic water partic-ularly in dry season | Normal (100% of Fami. N 2/M/F) | Excel-lent | — | Numbers of hand pump boreholes with more or less 30m deep. |
| 15 | Zugu 4,000 (Gummi) | ·Weathered meta-sediments with quartzite vein ·N-S wide fractured zone is apparent along the river | ·Deep weathering (more than 100m) along the river in accordance with lineament of fractured zone ·Probable high G/water potential along quarzite vein | ·Good ·E/C 380~470 | ·Serious shortage of water for domestic use during dry season | Normal (100% of Fami. N 1/M/F) | Excel-lent | T/W 1 (130m) T/W 2 (120m) 400ℓ/min by air lift | One deep well with motor pump, and gravity distribution system. Well depth 100~150m. |
| 18 | Takware 10,000 (Yauri) | ·Illo Formation ·Consists mostly of semiconsolidated fine to medium sand ·S/C : 70m³/d/m | ·Aquifer of medium to coarse grained sand probably lie in a depth of between 10 and 40m, and deeper than 70m. | ·Good ·E/C 930 | ·Shortage of water for domestic use during dry season | Less than Normal (100% of Fami. N 0.5/M/F) | Good ~ poor | — | 80 to 100m deep well with motor pump, and gravity distribution system. |
| 23 | Horo Birni 8,000 | ·Taloka Formation ·Consists mainly of semiconsolidated fine to medium sand ·S/C : 7~180m³/d/m | ·Numbers of minor aquifer are presumed between 30 and 200m depth, with frequently alternated by beds of clayey material | ·Good ·E/C·300 | ·Particularly strong desire for deep well construction, because numbers of shallow dug wells dry up during dry season | Strong (100 of Fami. N 5/M/F) | Fairly good | T/D(150m) 209ℓ/min T/W(120m) 380ℓ/min by air lift | Gravity distribu-tion system, with a water source of drilled test well. (small capacity motor pump) |
| 25 | Gudale 11,000 (Argungu) | ·Gwandu and Kalambaina Formations ·S/C : 0.3~216m³/d/m | ·Major aquifer consisting of sand presumably lies between 80 and 120m depth. | ·Good ·E/C 160~710 | ·Shortage of water for domestic use especially during dry season | Normal (100% of Fami. N /M/F) | Poor | — | 2 boreholes with depth of more or less 120m. Gravity distribu-tion system. |
| 26 | Chibike 5,000 (Argungu) | ·Upper members of Gwandu Formation ·S/C : 0.5~24m³/d/m | ·Major aquifer composed of coarse sand lies between 30 and 60m depth. | ·Good ·E/C 46 | ·Scatterd village with 3 settlements ·Shortage of water for domestic use especially in dry season | Normal (100% of Fami. N /M/F) | Poor | — | 60m deep borehole with small capacity power pump, and Gravity distribu-tion system for major settlement |

S/C : Range of specific capacity of existing wells nearby or surroundings of concerned area  E/C : Electric Conductivity in μυ/cm
N : Naira  /M/F : Per Month Per Family

Table 1-2 Result of Detailed Survey (3/3)

| | Village Name Population (Local Gov.) | Groundwater Potential: Hydrogeological Features | Groundwater Potential: Result of Geophysical Prospecting | Groundwater Potential: Expected W/Quality | Social and Health Environment | Willingness and Payability for Operation and Maintenance | Access-ibility | Result of Test Drilling and Well Discharge | Recommendable Water Supply System |
|---|---|---|---|---|---|---|---|---|---|
| 32 | Gendene 3,100 (~11,000) (Bagudo) | ·Illo Formation composed mostly of semi-consolidated fine to coarse sand ·S/C : 1.8~53m³/d/m | ·Major aquifer being composed of coarse sand is expected in deeper than 60m. | ·A little poor ·E/C 1300 | ·Scattered village with a major settlement near to the River Niger. ·Bridge and new road are under construction as of 1989 ·Shortage of water in dry season | Normal (100% of Fami. N 1/M/F) | Good | — | One borehole with gravity distrubu-tion system for major settlement |
| 34 | Soro 4,500 (Silame) | ·Lower members of Gwandu Forma-tion and Kalambaina For-mation ·S/C : 1.4~59m³/d/m | ·High G/water potential is expected from frequently alternated beds. Major aquifer is sand or limestome which lies in deeper portion than 40m. | ·Good ·E/C 300 (Guwandu Formation) | ·Shortage of domestic water in dry season | Strong (100% of Fami. N 3/M/F) | Good | T/W (150m) 900ℓ/min by air lift | Gravity distribu-tion with a sourse of drilled test well |
| 42 | Sambawa 8,000 (Jega) | ·Gwandu Forma-tion composed mostly of sandy and clayee material ·S/C : 1.3~93m³/d/m | ·Frequently alternated sand and silty material. Major aquifer proba-bly lies deeper than 110m BGS. | ·Good ·E/C 295~440 | ·Shortage of domestic water in dry season | Normal (100% of Fami. N 1/M/F) | Good ~ poor | — | One borehole with a depth of more than 110m. and gravity distribution system |
| 43 | Kimba 6,200 (Jega) | ·Taloka Formation ·S/C : 1.5~42m³/d/m | ·Very high G/water potential is expected by abundance of gravelly material overlain/alternated with other beds. | ·Good ·E/C 140~680 | ·Shortage of domestic water in dry season | Normal (100% of Fami. N 1/M/F) | Good ~ poor | — | One borehole of 120 to 150m deep, and gravity distribution system |
| 44 | Kuka Kogo 3,500 (Jega) | ·Illo Formation ·S/C : 7~160m³/d/m | ·High G/water potential is expected owing to alternation of fine sand, gravelly sand and silty material. Major aquifer may exist between 30 and 100m deep. | — | ·Diseases caused by river water drinking | Normal (100% of Fami. N 2/M/F) | Good | T/W (113m) 800ℓ/min by air lift | Gravity distribution system using drilled test well as a source. |
| 46 | Mallamawa 10,000 (Sokoto) | ·Kalambaina and Wurno Formations ·S/C : 0.7~5.6m³/d/m | ·Poor G/water potential due to the formations composed mostly of silty or clayey materials down to 200m deep. | — | ·Shortage of domestic water | Normal (100% of Fami. N 1/M/F) | Good ~ poor | — | Numbers of shallow/deep hand pump wells as point sources |
| 47 | Samalu 4,500 (Sokoto) | ·Gwandu and Kalambaina For-mations ·S/C : 1.7~79m³/d/m | ·Good aquifer of limestome or marly limestome is underlain between 20 and 40m deep. Lower portion than that is also supposed to be full of aquifers. | ·Good ·E/C 59~81 (But only in Gwandu Formation) | ·Shortage of domestic water | Normal (100% of Fami. N 1~2/M/F) | Good | — | One borehole of 100~150m deep, and gravity distribution system |

S/C : Range of specific capacity of existing wells nearby or surroundings of concerned area
N : Naira

E/C : Electric Conductivity in μυ/cm
/M/F : Per Month Per Family

## 1-3 Additional Experimental Survey in the Basement Area

An additional detailed hydrogeological survey was carried out in Zugu, one of the candidate villages included in the basement complex area (Fig. 1-1). The purpose of this survey work was :

- to brush up the hydrogeological survey methodology
- to introduce the method of seismic refraction in hydrogeologic investigation,
- to review the method of site selection for the drilling based on the comprehensive analyses of all of the results including every different survey, and
- to establish the appropriate guideline for the groundwater investigation, particulary in the basement complex area, a so-called difficult area.

In order to accomplish the above-mentioned purpose, the following activities were undertaken ;

- Hydrogeological field reconnaissance with remote sensing
- Survey line fixing work (checkerboard pattern with 100m intervals), and a revision of the topographic map prepared in the previous stage
- Transient electro-magnetic (TEM) survey and its rough analysis
- Electric resistivity sounding, the field operations involved, the resistivity classification by depth, and preparation of the iso-depth map of fresh bedrock, which established the major basis for determination of the drilling points
- Seismic refraction survey, the field operations involved and the explanation of the principle and analytic procedures.
- Test well construction and pumping test to confirm the lithologic formation and yielding capacity of the wells

Survey results are included in this volume.

## 2. TRANSIENT ELECTROMAGNETIC SURVEY (TEM SURVEY)

According to the plan of operation for the Stage II an electro-magnetic technique using an EM-37 survery kit was to be applied in selected sites for a comparatively macro-scopic survey, focusing mostly on the basemet complex area. The field works of this TEM survey, however, were carried out only at the two sites (Ruwan Bore and Tunga Ardo) in the basement complex area, due to a breakdown of the equipment (Transmitter), of which repars took about 30 days.
Techniques of measuring, analysis and maintenance were transfered to a limited number of 2 persons of the TEM, through actual field operations, since operations/analysis of the TEM survey is somewhat difficult for amateurs.

### 2-1 The Principles of TEM

Transient electro-magnetic systems (TEM) with their inherent ability to generate highly valuable diagnostic data have been increasingly used for exploring greater depths, improving rejection of conductive overburden or host rock response and enhancing definition of ore-bearing structures.
The principle of transient electro-magnetic systems is to lay a large loop (Figure 2-1) in the area to be explored and then cause a steady current to flow in the loop for a sufficiently long time to allow the eddy currents generated at turn-on time to dissipate. This current is then sharply terminated in a controlled fashion (Figure 2-2(a)). A rapid reduction in the transmitter current (which means a corresponding rapid reduction in the transmitter primary magnetic field) induces an electromotive force (emf) in nearby conductors. The magnitude of this emf is in proportion to the time rate-of-change of the primary magnetic field at the conductor. A large emf of short duration is obrained by reducing the transmitter current to zero in a short time (Figure 2-2(b)). This emf causes eddy currents to flow in the conductor with a decay that is afunction of the conductivity, size and shape of the conductor. The decay currents in turn generate a proportional secondary magnetic field (Figure 2-2(c)), whose time rate-of change is measured by a receiver coil.
The amplitude of transient decay is measured at numerous intervals and at many cycles of the signal pulses to reduce the effect of noise.

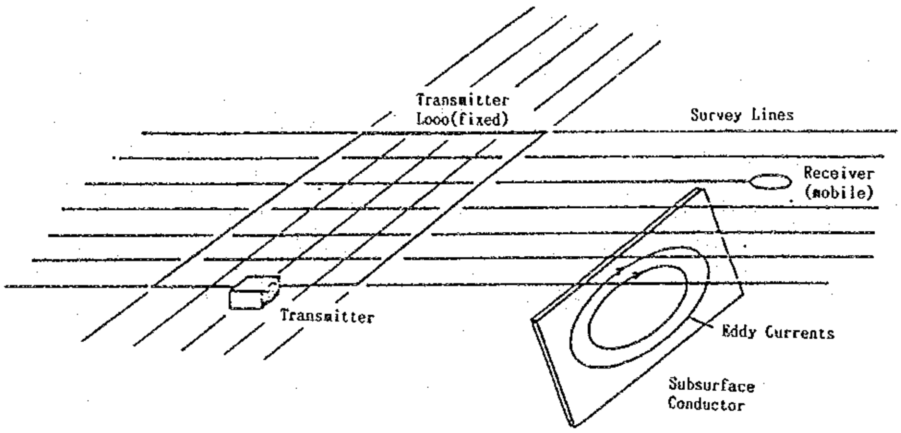



Fig. 2-1 Survey Configuration

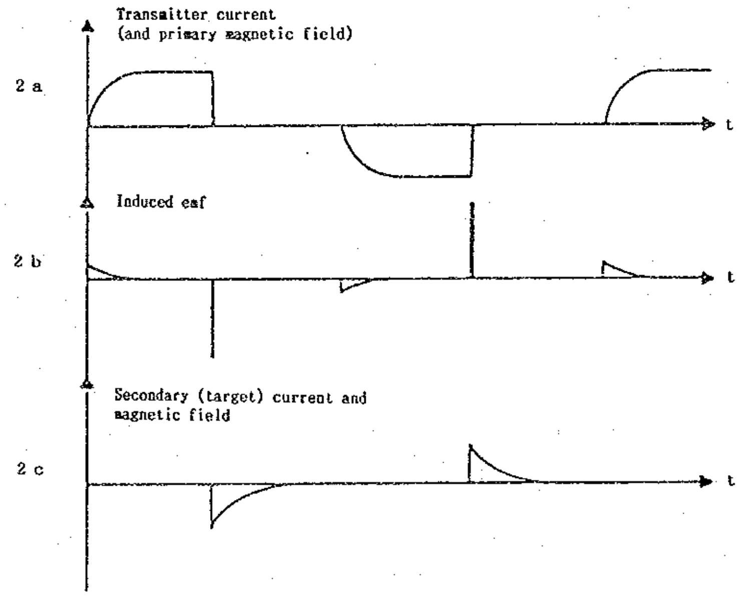



Fig. 2-2 System Waveforms

Conductive targets usually produce signals with small initial amplitude that decay relatively slowly with time. Poor conductors yield signals with high initial amplitude but which decay rapidly. Initially after turn-off, the eddy currents flow on the surface of the conducting body. A stage is then reached at which the eddy currents have diffused into and are completely distributed within the target body. This period is referred to as the "late time". Measurements carried out at this stage yield very diagnostically useful information about both the shape and conductiviry of the targe.
In late time the voltage output at the receiver coil, e(t), is given by the equation :

$$e(t) = \frac{KM}{p^{3/2} \cdot t^{5/2}}$$

where

M = transmitter dipole moment
p = ground resistivity in ohm-meters
t = time in seconds
and k = a constant

Inverting the above equation gives us an apparent resistivity of the ground as a function of time as shown below :

$$pa(t) = \frac{KM}{e(t)}^{2/3} \cdot \frac{1}{t^{5/3}}$$

Thus, by simply measuring the output voltage at the receiver coil we can obtain an apparent resistivity. In homogenous ground, this apparent resistivity is not a function of time but is equal to the true resistivity of the homogenous half space (HHS). However, in heterogenous ground this apparent resistivity is a function of time.

## 2-2 Measuting System

The EM-37 measuring system and operating procedure are shown in Figures 2-3 and Figure 2-4.
Depending on the geological terrain, two modes of survey are employed: a

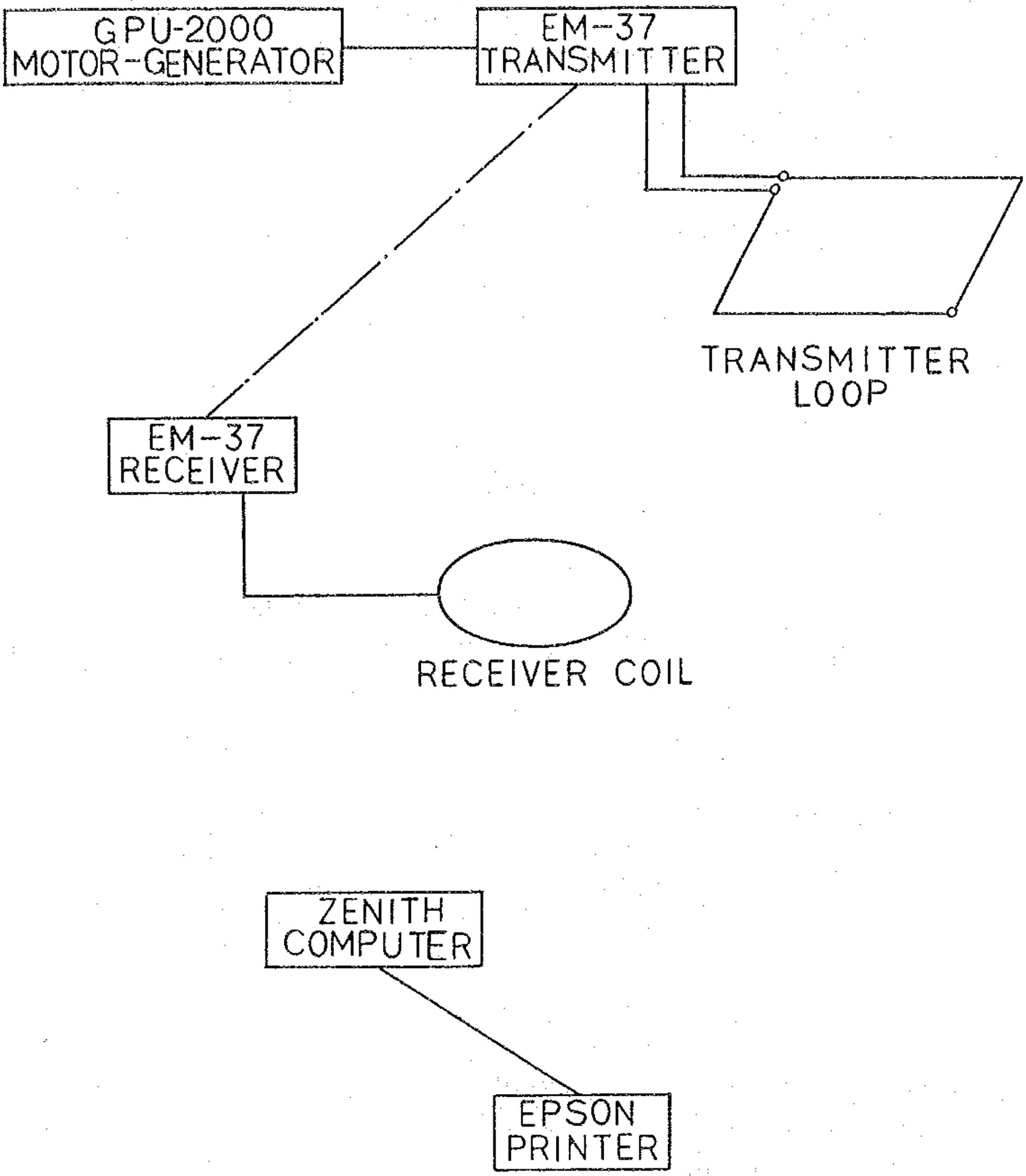



Fig. 2-3 Measuring System

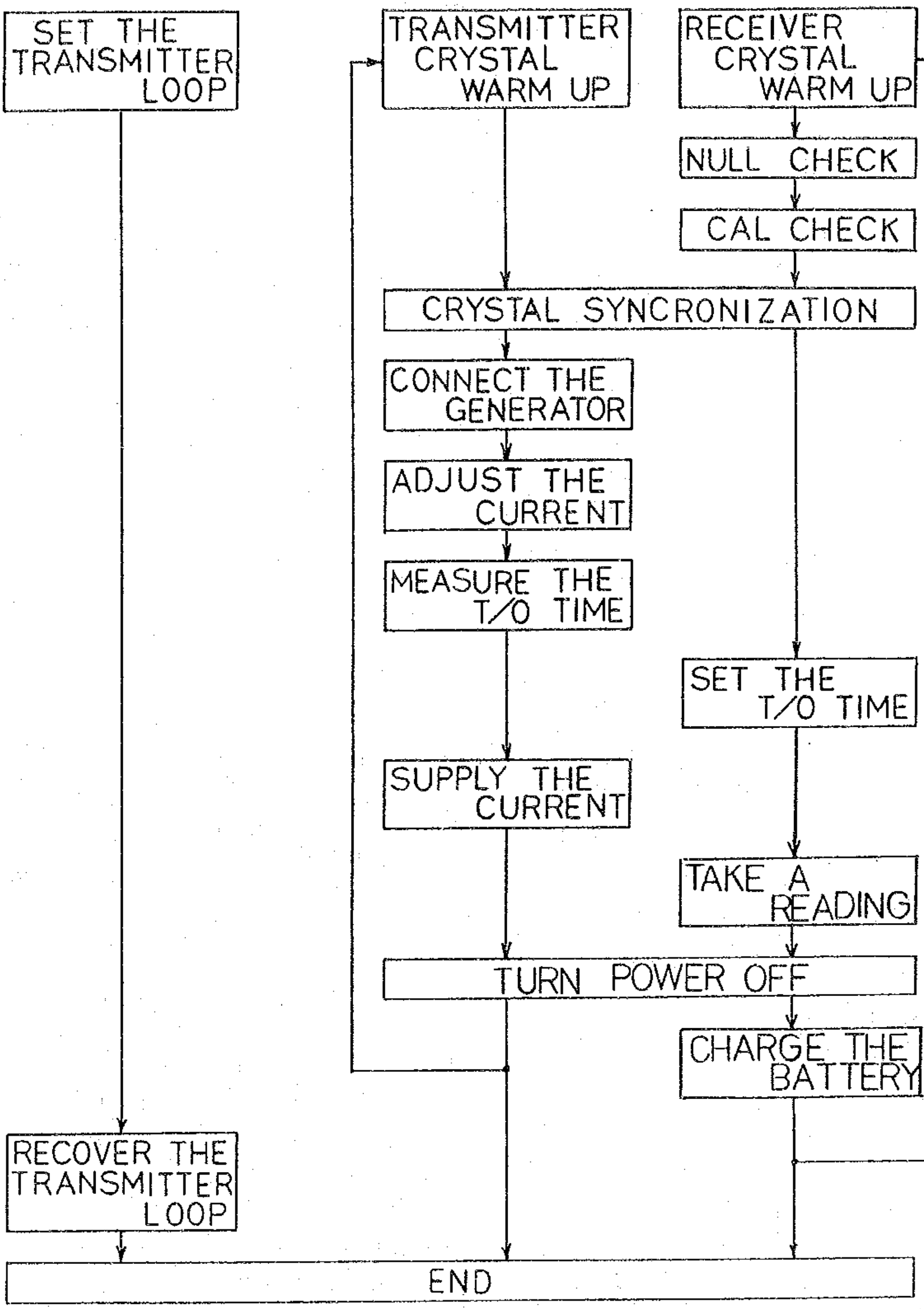



Fig. 2-4 EM-37 Operating Procedure

fixed transmitter loop and an unfixed transmitter loop mode.
In the basement complex area, the fixed transmitter loop mode is employed. In this mode, a large loop is laid down in the vicinity of the survey area and the receiver is moved to different measurement stations along mapped-out traverse lines.
In the sedimentary terrain, the unfixed transmitter loop mode is used. In this mode, a small transmitter loop is laid down and the receiver is placed at the center of the loop. After measurement, the entire set-up is moved to the next measurement station while maintainig the same transmitter-receiver distance.
In either mode, one operator each is required for the transmitter and receiver. Four laborers are needed for loop laying, and a fifth is needed to guard the equipment. It is desirable to have a radio link between the transmitter and receiver operators, especially in the fixed transmitter loop mode.

## 2-3 Results of Field Work

TEM surveys were carried out in the Ruwan Bore and Tunga Ardo areas. Respectively for these areas, the survey stations and the data obtained from them are shown in Figures 2-5 and 2-7, "Location of EM Survey Points", and in Figures 2-6 and 2-8, "TEM Traverse Data Profile". The TEM traverse data profiles show survey stations along traverse lines on the abscissa and recorded voltage at the respective stations divided by transmitted current value on the ordinate.

The TEM survey at Ruwan Bore was carried out at only two stations, this as a test run of the equipment. The TEM traverse data profile shows not only recorded data but also the results interpreted by the TEMIX computer program supplied with the EM-37 kit.

Resistivity in the Ruwan Bore area is high so that the received voltage, is small, especially being collected in late time, in channels greater than seven. In order to obtain greater depth of penetration, it is required to obtain data in late time. However due to electro-magnetic noise in the area, we could not obtain noise-free data in late time at lower transmitting frequencies.

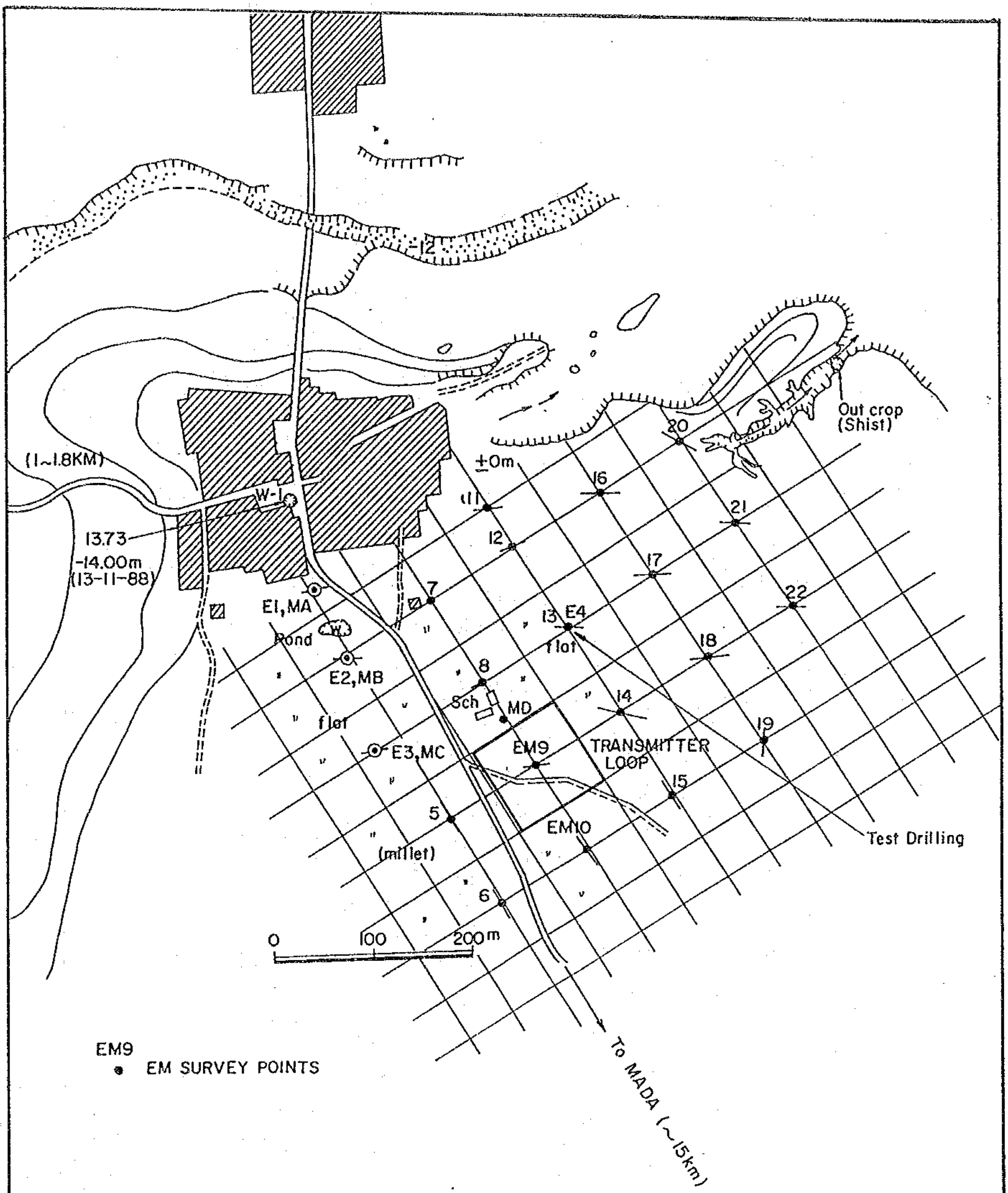



Fig. 2-5 Location of the Survey Points (Ruwan Bore)

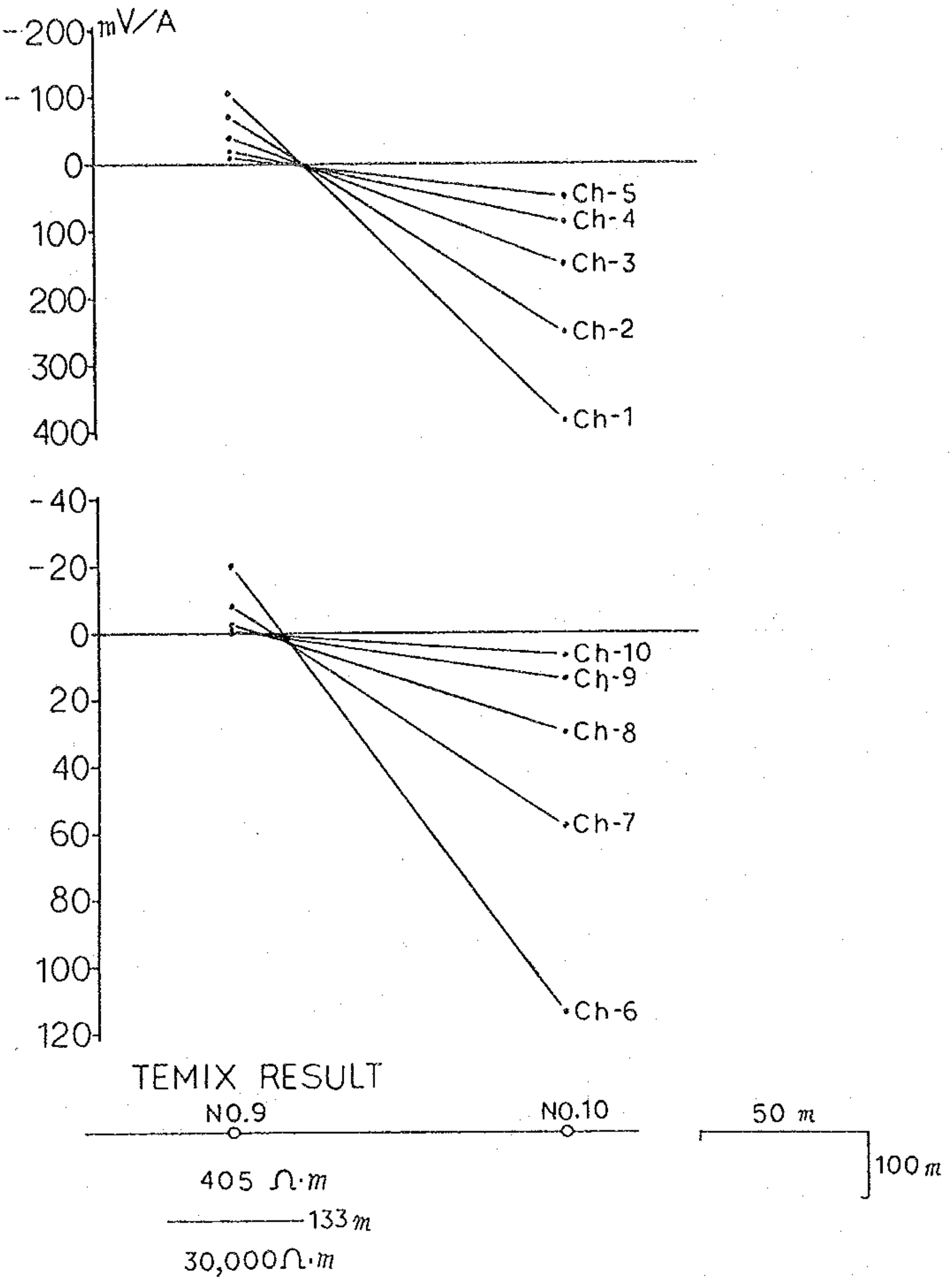



Fig. 2-6 TEM Traverse Data Profile (Ruwan Bore)

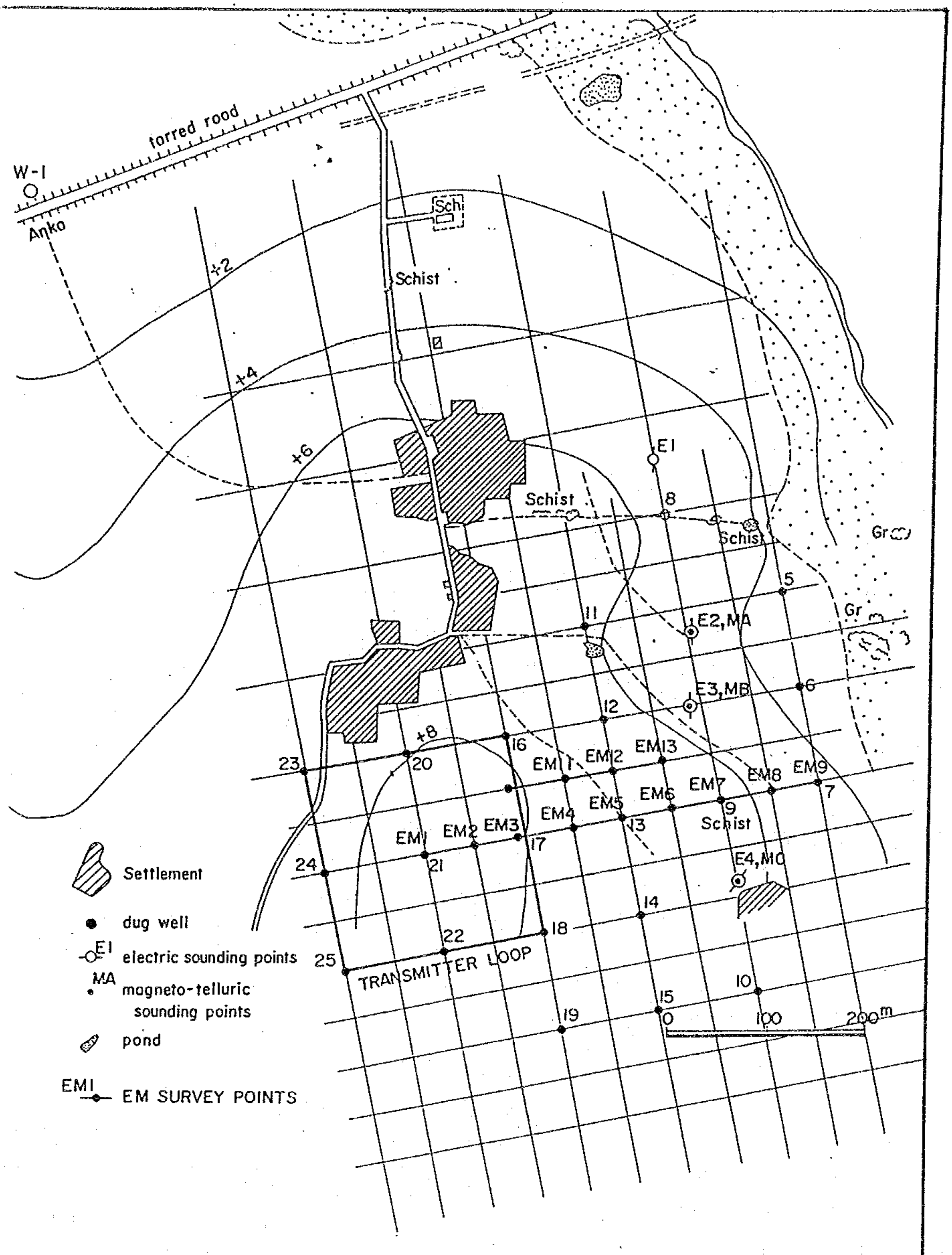



Fig. 2-7 Location of the EM Survey Points (Tunga Ardo)

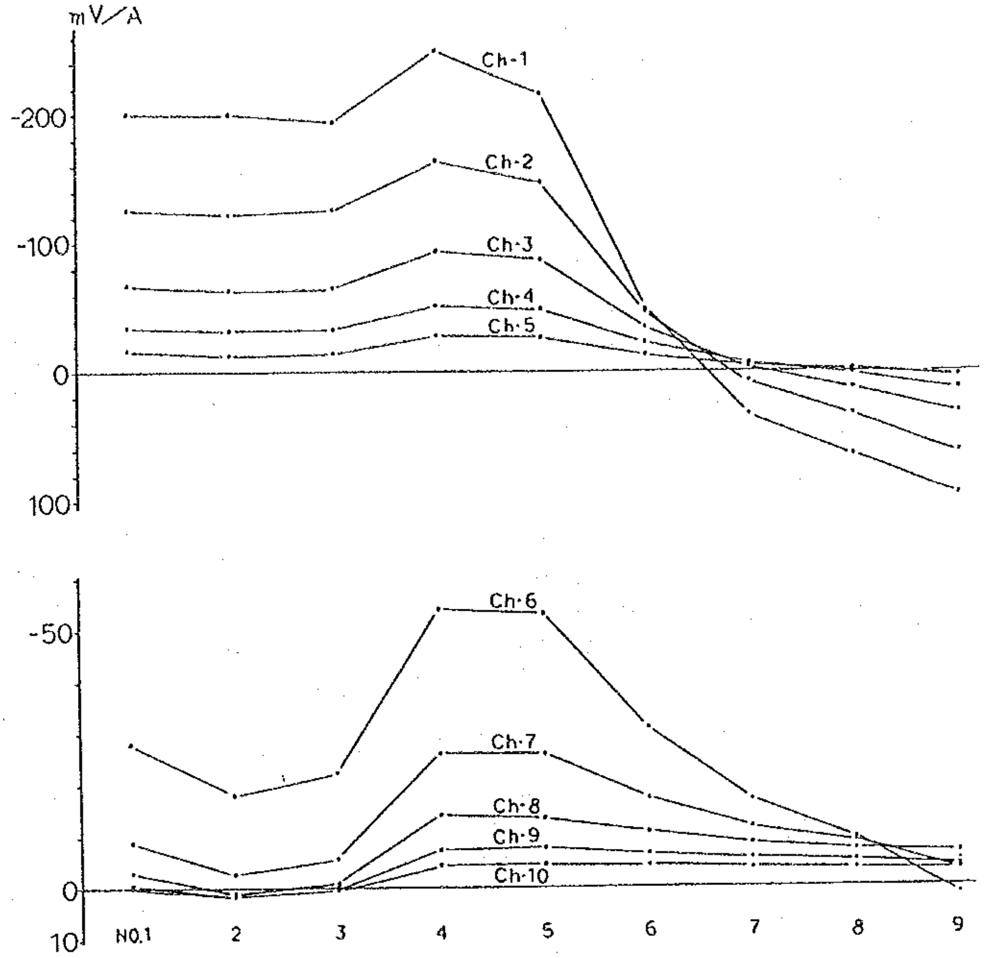



Fig. 2-8 (1)  TEM Traverse Data Profile (Tunga Ardo)

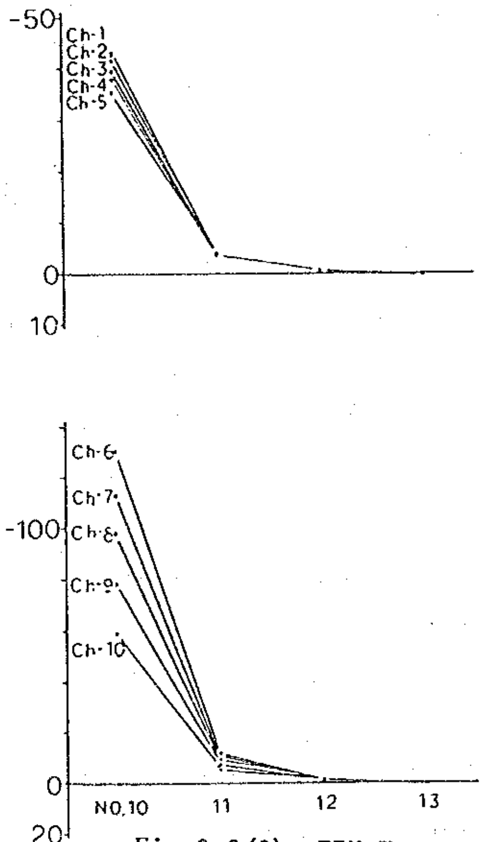



Fig. 2-8 (2)  TEM Traverse Data Profile (Tunga Ardo)

The survey results are in the Data Report as the field records and the TEMIX outputs. Because resistivity in the Ruwan Bore area is very high, the results lack resistivity data at shallow depths.

As shown in Figure 2-7, the transmitter loop used in the Tunga Ardo area is 200m by 200m, so that the transmitter dipole moment of the area is much greater than that in the Ruwan Bore area.

The survery stations in the Tunga Ardo area were arranged along a line-cutting square across a presumed general geological trend. First, a survey line connecting atation EM-1 and station EM-9 was established as a main line,then a parallel subordinate line connecting station EM-10 and station EM-13 was set. Stations EM-1,-3,-5,-7, and -9 were set at the same locations as electrical resistivity sounding points 21, 17, 13, , and 7, respectively.

TEM data obtained along the main traverse line show a significant difference at stations EM-4 and -5. The recorded voltages of channels 1 through 5 change polarity from negative at stations EM-1 through EM-6 to positive at stations EM-7 through EM-9. The recorded voltages of channels 6 through 10 show a similar pattern. TEM data obtained along the subordinate traverse line do not reflect such a change in polarity, but rather a decrease in voltage with distance from the transmitting loop. As shown in the Data Report, the signals recorded beyond channel 11 are very small and may be contaminated by noise.

## 2-4 Results of Interpretation

The data obtained from each survey station were transferred to a computer, and the TEMIX program was used to interpret transient curves into one-dimensional vertical columns. A typical flowchart of TEMIX software is given in Figure 2-9. The data along the traverse lines were interpreted two-dimensionally by MOTEM program, also supplied with the EM-37. The outputs of the TEMIX and MOTEM programs are given in the Data Report.

The interpreted results form Ruwan Bore are shown in Figure 2-6. Based on the general geology of the study area, we infer that the geology beneath station EM-9 is an about 130m-thick weathered layer underlaying by resistive fresh basement rock. The resistivity of the area is very high, so that the deep weathering zone cannot be mapped in detail through TEM as it can be through electreical resistivity sounding.

Two-dimensional interpretation is carried out for the data between stations EM-1 and EM-9 along the traverse line, and the data at staion EM-1 are interpreted one-dimensionally by the TEMIX program in the Tunga Ardo area. The results are shown in Figure 2-10.

The one-dimensional interpretation at station EM-1 indicated that the geology beneath the station is similar to that in the Ruwan Bore area, with a weathered layer about 50m thick overlaying resistive fresh basement rock.

For the two-dimensional interpretation by MOTEM, the following initial model is assumed.

1) Resistivity of the environment is assumed to be 175,000Ω ohm-m.

2) A thin sheet with a longitudinal conductivity of 0.25 S, the same longitudinal conductivity as the first conductive layer at station EM-1,is assumed to extend to a depth equalling half of that of the first layer.

Thus, the initial model constructed is as if the resultant one-dimensional structure at station EM-1 was continuously existent along the entire traverse line.

The position and conductance of vertical thin plate conceived of as lying below the formerly mentioned horizontal sheet of 0.25 S were adjusted in the simulation to fit collected data. The model given by the MOTEM program which fits best was the one in which the vertical plate was positioned between stations EM-4 and EM-5, with a longitudinal conductivity at 2 S. For calculation, if the thickness of the shin plate was assumed to be 50m, its resistivity was assumed to be 25 ohm-m. This conductive shin plate was assumed to represent a fractured zone filled with groundwater and clay.

We interpret that the geology of the area is resistive basement rock overlain by a conductive weathered layer with a thickness of 50m.

Total conductivity over the resistive basement rock by resistivity sounding is mapped in Figure 2-11, Total Conductivity Map. Toatl conductivity is the sum of the longitudinal conductivity of each layer over the resistive basement rock. It is greater than 150 mS along the main traverse line. A thin conductive

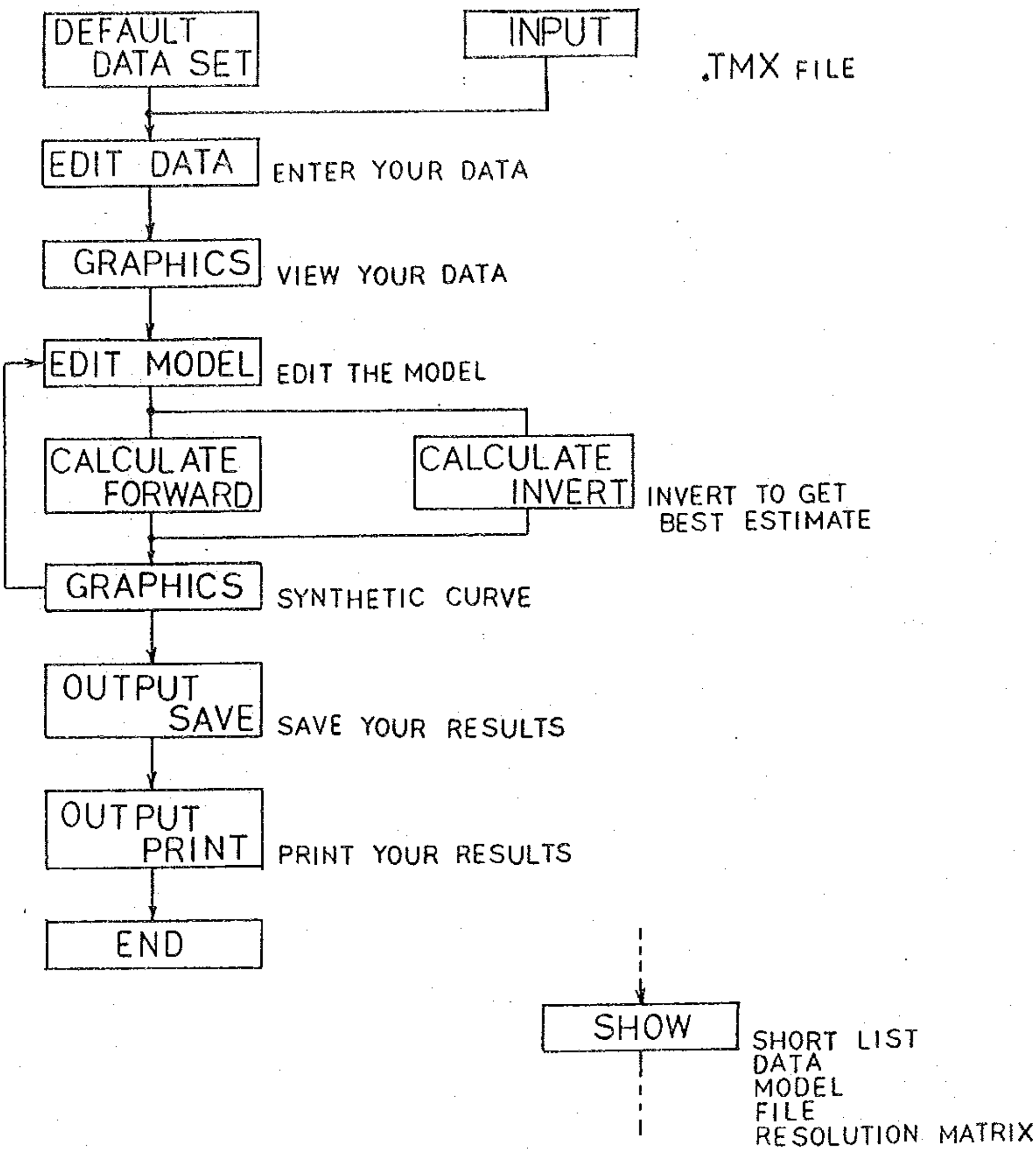



Fig. 2-9 Typical Flow Chart of Temix Software

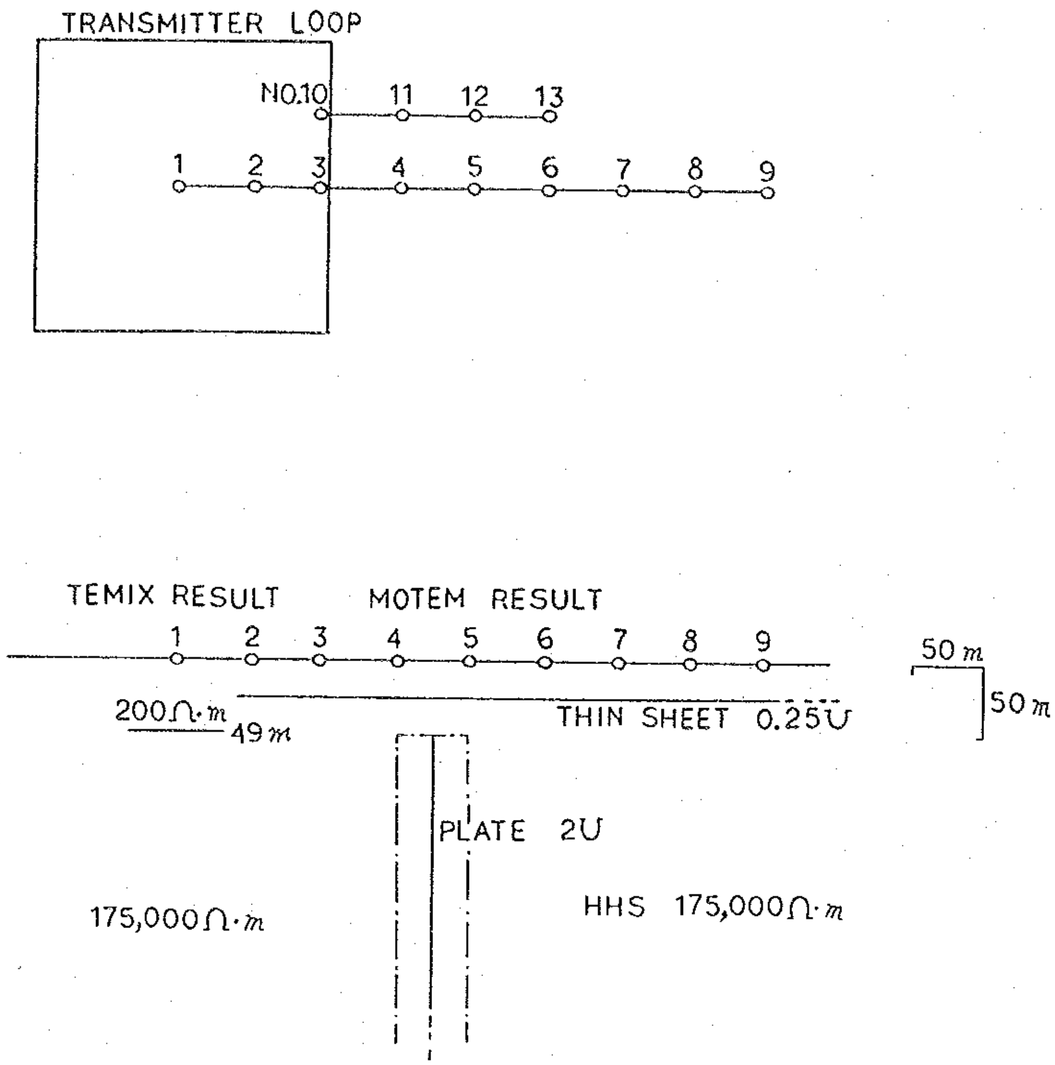



Fig. 2-10 Computer Modeling of Tunga Ardo

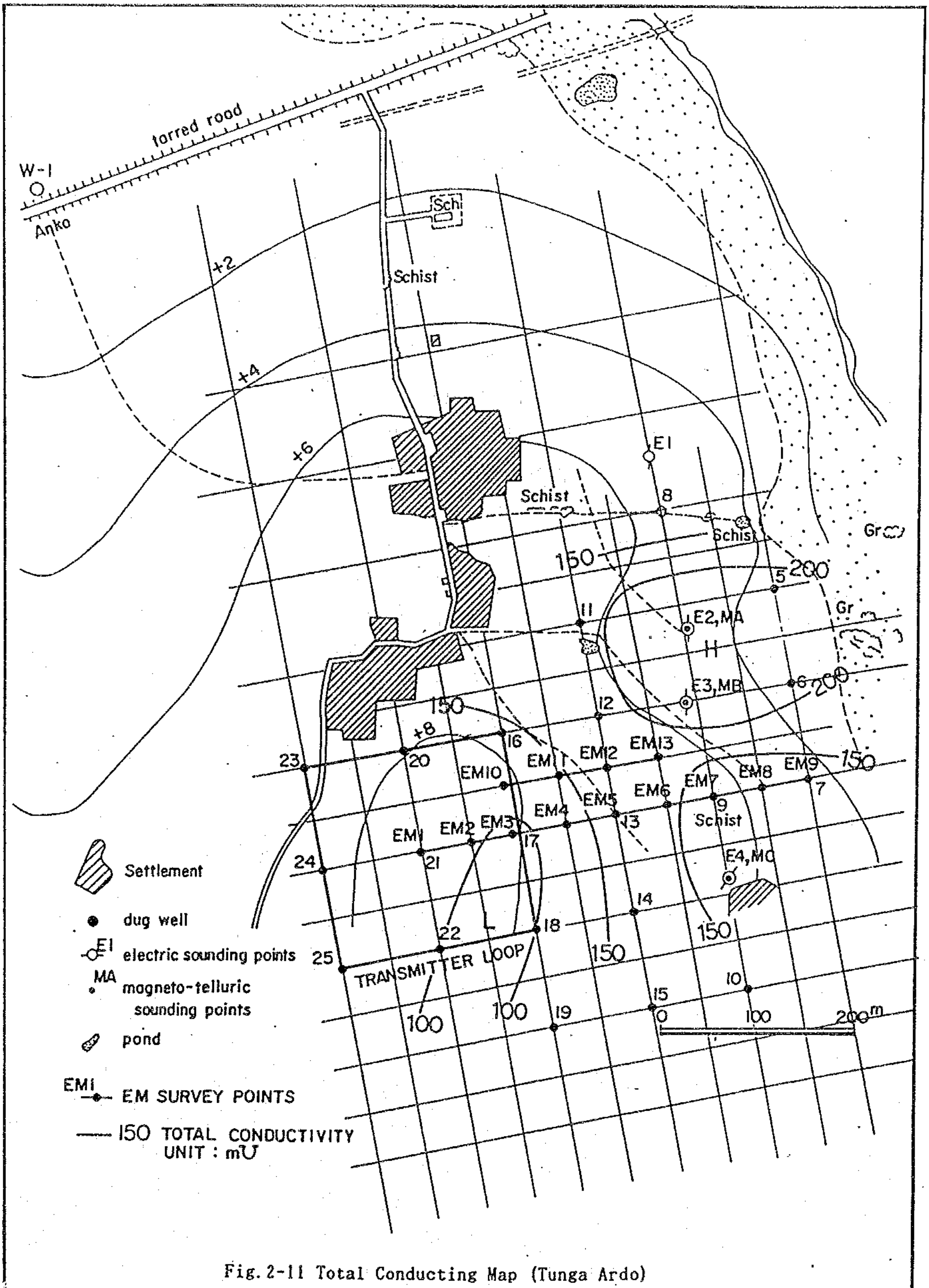



Fig. 2-11 Total Conducting Map (Tunga Ardo)

plate is interpreted to intrude into the basement. The results are consistent with both the TEM survey and resistivity soundings.

It took about two hours to set up the transmitter loop for the TEM survey in the Tunga Ardo area, and it took about 15 to 30 minutes to measure at each station. Overall, then,TEM measurement is faster than that of resistivity sounding, which takes about two hours to measure at each point. However, as stated above, resistivity sounding can yield more detailed interpretation resistivity layers at shallow depths than a TEM survey.

With the advantages that TEM offers, we believe that the most efficient approach to the evaluation of an area's geology is to investigate in this sequence : TEM survey, resitivity sounding, and, finally, seismic sounding. This approach should be tested and confirmed.

## 3. SEISMIC REFRACTION SURVEY

Seismic refraction methods use seismic waves to determine the thickness and extent of aquifer materials where the formations are arranged so that the density increases with each successively lower layer. Seismic surveys are based on the velocity distribution of artificially generated seismic waves in the ground. Seismic waves can be produced by hammering on a metal plate, by dropping a heavy ball, or by using explosives. Energy from these sources is transmitted through the ground by elastic waves. The amount of energy is relatively low in comparison with the energy released by an earthquake, so the disturbance cannot be detected far from the point where the wave is initiated. The waves are called elastic because, as the waves pass a point in the rock, the particles are momentarily displaced or distorted, but immediately return to their original position or shape after the wave passes. Three types of waves can be created: compressional (P) waves, share (S) waves, and surface waves. The arrival of a seismic wave is detected by geophones (seismometers) placed firmly in the ground. Compressional waves are the first to arrive at the geophones, and therefore are the most useful in seismic surveys. In general, the higher the density and elasticity of the rock unit, the faster the P wave will be transmitted. The velocity is much less and the energy is dissipated more quickly if the material is unconsolidated or poorly consolidated.

Three distinct paths are taken by compressional waves in the ground: direct (surface), refracted, and reflected. For a two-layered setting, these three wave paths are as shown in Figure 3-1. The exact arrival time of the seismic wave will depend on which path it takes and the density of the material. A single seismic impulse can be recorded as three separate arrivals at the geophone. In practice, however, only the first arrival can be readily recognized. At geophone-seismic source spacings generally used in refraction surveys, direct waves usually arrive at the geophone after refracted and reflected waves because surface materials are normally less dense than deeper materials. Because surface waves will not provide information about subsurface aquifer conditions, refracted and reflected waves are the most valuable for groundwater investigations. In most geologic settings, more than two distinct rock or sediment layers exist, thereby complicating the seismic analysis.

During a refraction survey, the investigator measures the time the seismic wave takes to reach one or more geophones placed at known distances from the seismic source. By plotting the distance-time relationship, the depth of several geologic units can be estimated at a particular site as long as each successively lower unit has a higher seismic velocity. The elapsed time and the distance traveled also provide information on the type of geologic material.

Each geologic formation has a characteristic seismic velocity that affects arrival time. Some representative seismic velocities are given in Table 3-1. In the field, local seismic velocities can also be estimated by measuring the travel time to and from a particular formation whose depth is already known from a drilling log. If a waterfilled well is available, one or more geophones can be lowered into the well at successively greater depths to obtain travel times from seismic source placed at the surface (Mooney, 1981). Seismic velocities can also be obtained by conducting refraction surveys.

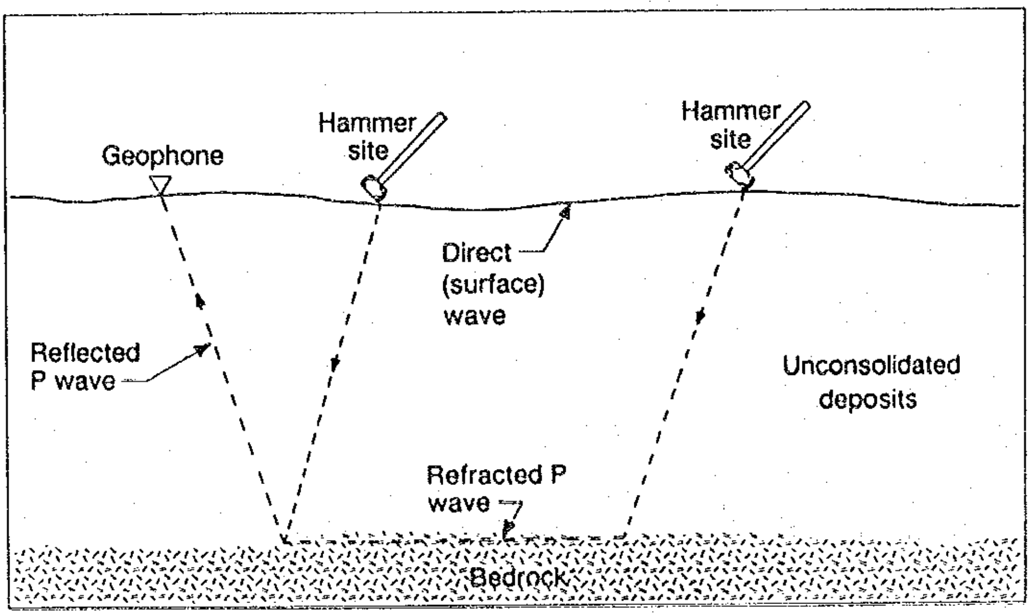



Fig. 3-1 Waves from a seismic disturbance can travel as surface, reflected, and refracted waves. In water well exploration, analyses of refracted and reflected waves can determine the depth to bedrock at a potential drilling site.

Seismic investigations are carried out from a point where borehole information is available or where the stratigraphy has been determined through other geophysical methods. To locate the water table with the refraction method, the water table should be well above the contact between the bedrock and the overlying alluvial deposits (Wallace, 1970). If seismic exploration methods are used in conjunction with other geophysical methods, exploratory drilling costs can be minimized.

In the seismic reflection method, the seismic wave produced by a hammer blow or other seismic source reflects off the bedrock and returns directly to the geophone, where the elapsed time is recorded. In order to maximize the reliability of the reflected wave energy, hammer stations are usually not more than 30 ft (9.1m) from the geophone.

The most difficult problem with the reflection method is that the reflected wave is never the first to appear on the seismic record. Therefore, on an ordinary receiving device its arrival is almost impossible to recognize among the multitude of other wave arrivals. This problem can be overcome by using signal enhancement, which permits the operator to separate the primary reflected wave from other waves. In practice, the operator strikes a hammer plate one or more times at five to ten sites that are located within 30 ft (9.1 m) of the geophone. The seismic signals received from these sites are summed automatically by the seismograph. When the signals from several hammer sites are summed, the surface waves and other extraneous impulses which ordinarily obscure the primary reflected wave are canceled out, leaving the primary reflected wave prominently displayed on the cathode ray tube. This wave travels essentially the same distance even if the hammer sites are moved, as long as they are not too far from the geophone and the depth to bedrock is considerably greater than the spacing of the hammer sites.

Table 3-1 Approximate Range of Velocities of Compressional (P) Waves for Representative Materials Found in the Earth's Crust

| Material | Velocity* | |
|---|---|---|
| | ft/sec | m/sec |
| Weathered surface material | 1,000 - 2,000 | 305 - 610 |
| Gravel, rubble, or sand (dry) | 1,500 - 3,000 | 457 - 915 |
| Sand (wet) | 2,000 - 6,000 | 610 - 1,830 |
| Clay | 3,000 - 9,000 | 915 - 2,740 |
| Water (depending on temperature and salt contenct | 4,700 - 5,500 | 1,430 - 1.680 |
| Sea water | 4,800 - 5,000 | 1,460 - 1,520 |
| Sandstone | 6,000 - 13,000 | 1.830 - 3,960 |
| Shale | 9,000 - 14,000 | 2,740 - 4,270 |
| Chalk | 6,000 - 13,000 | 1,830 - 3,960 |
| Limestone | 7,000 - 20,000 | 2,130 - 6,100 |
| Salt | 14,000 - 17,000 | 4,270 - 5,180 |
| Granite | 15,000 - 19,000 | 4,570 - 5,799 |
| Metamorphic rocks | 10,000 - 23,000 | 3,050 - 7,010 |
| Ice | 12,050 | 3,670 |

* The higher values in a given range are usually obtained at depth.

(Jakosky, 1950)

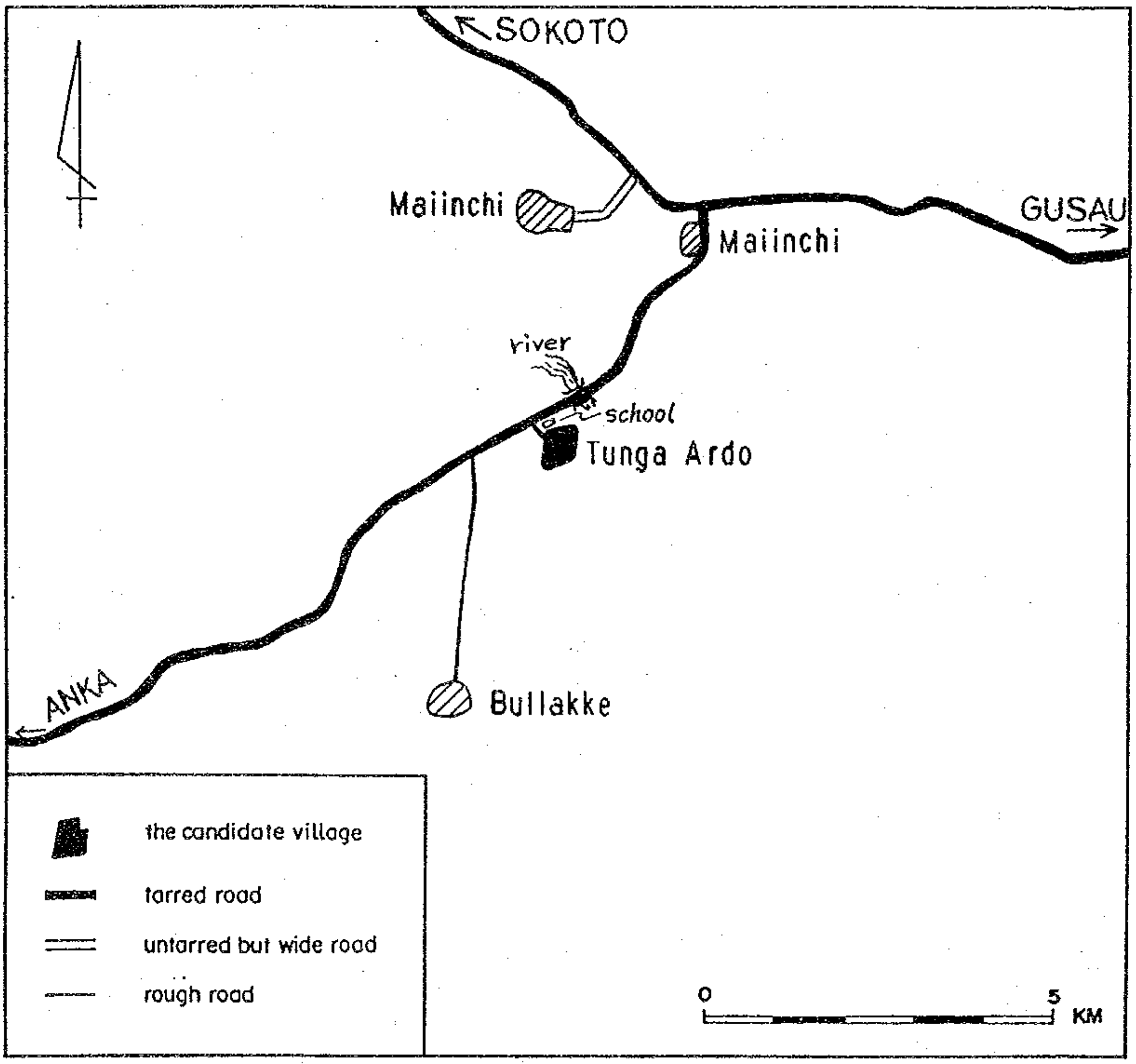
(Quated from "Groundwater and Wells, FLETCHERE, G. D. Edit")

# 4. HYDROGEOLOGICAL MAPS

# The Study for Groundwater Development in Sokoto State

VILLAGE : Tunga Ardo

Village No. 1

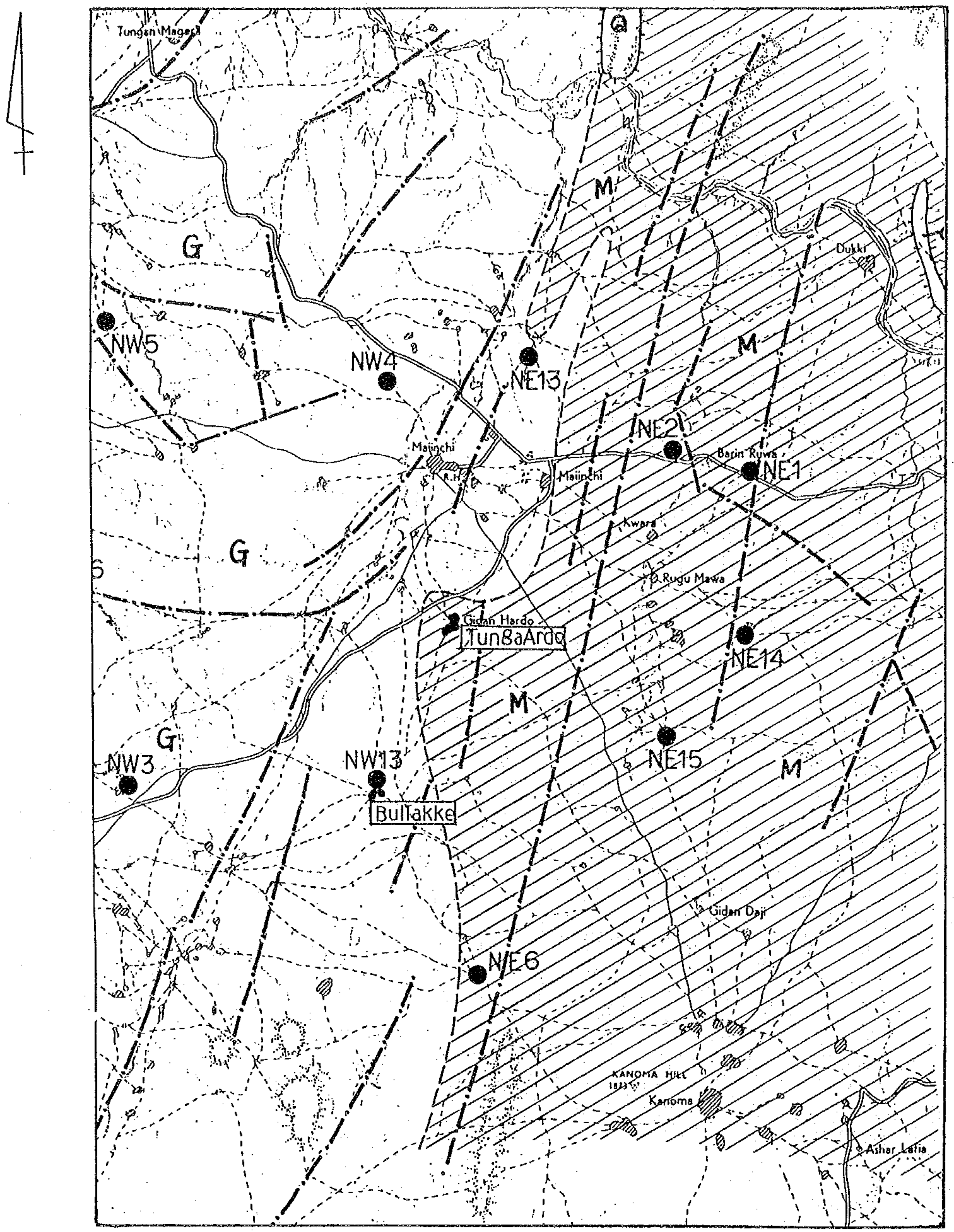



## LOCATION MAP

( 1/100,000 Sheet ______ )

# GEOLOGICAL MAP

## Tunga Ardo




1/100,000 0 50 km

G Older Granite

M Meta-sediments

Q Quartzite

Escarpment

Lineament

SW 16 Existing Boreholes

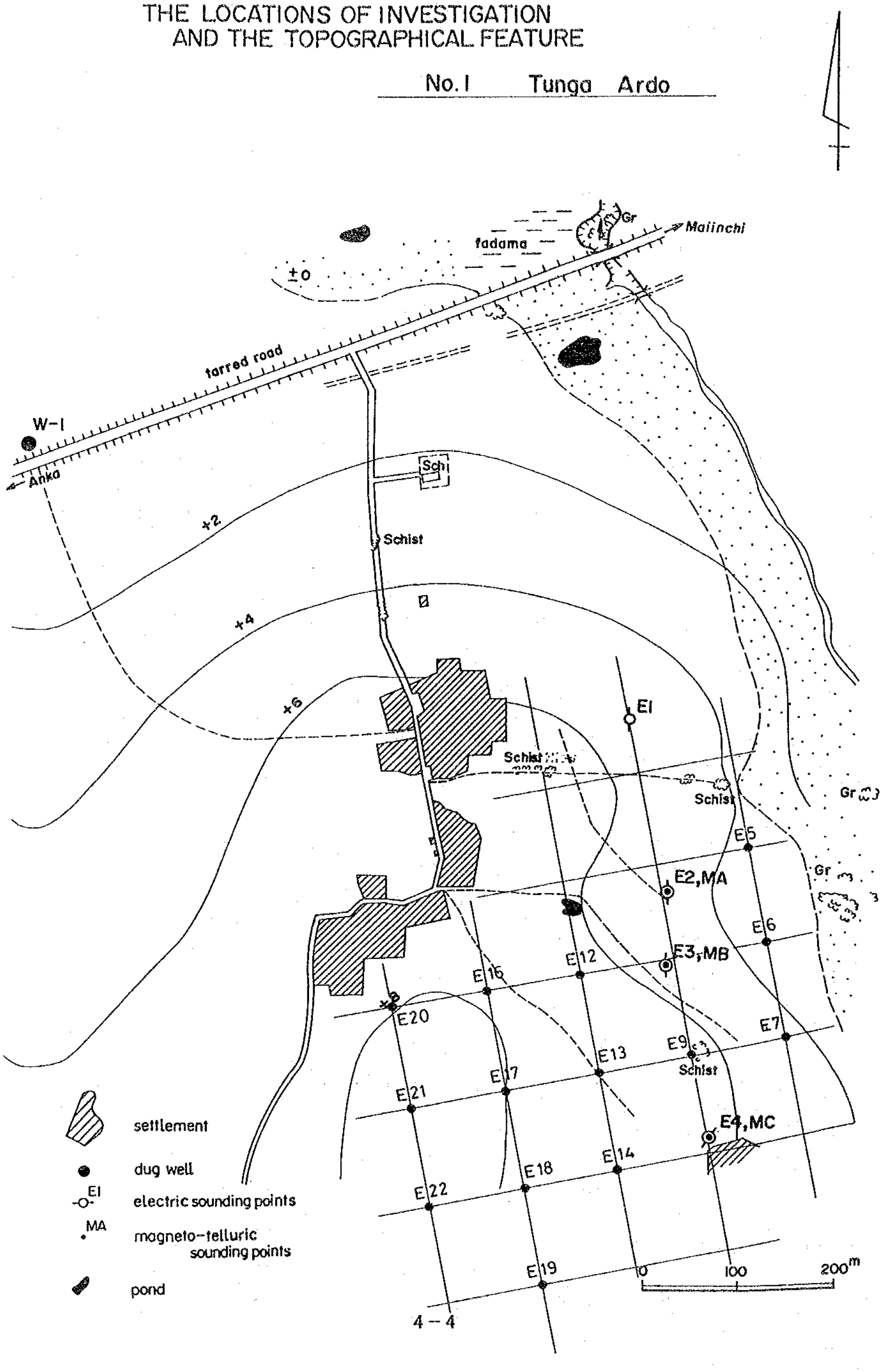
DATA OF EXISTING BOREHOLES

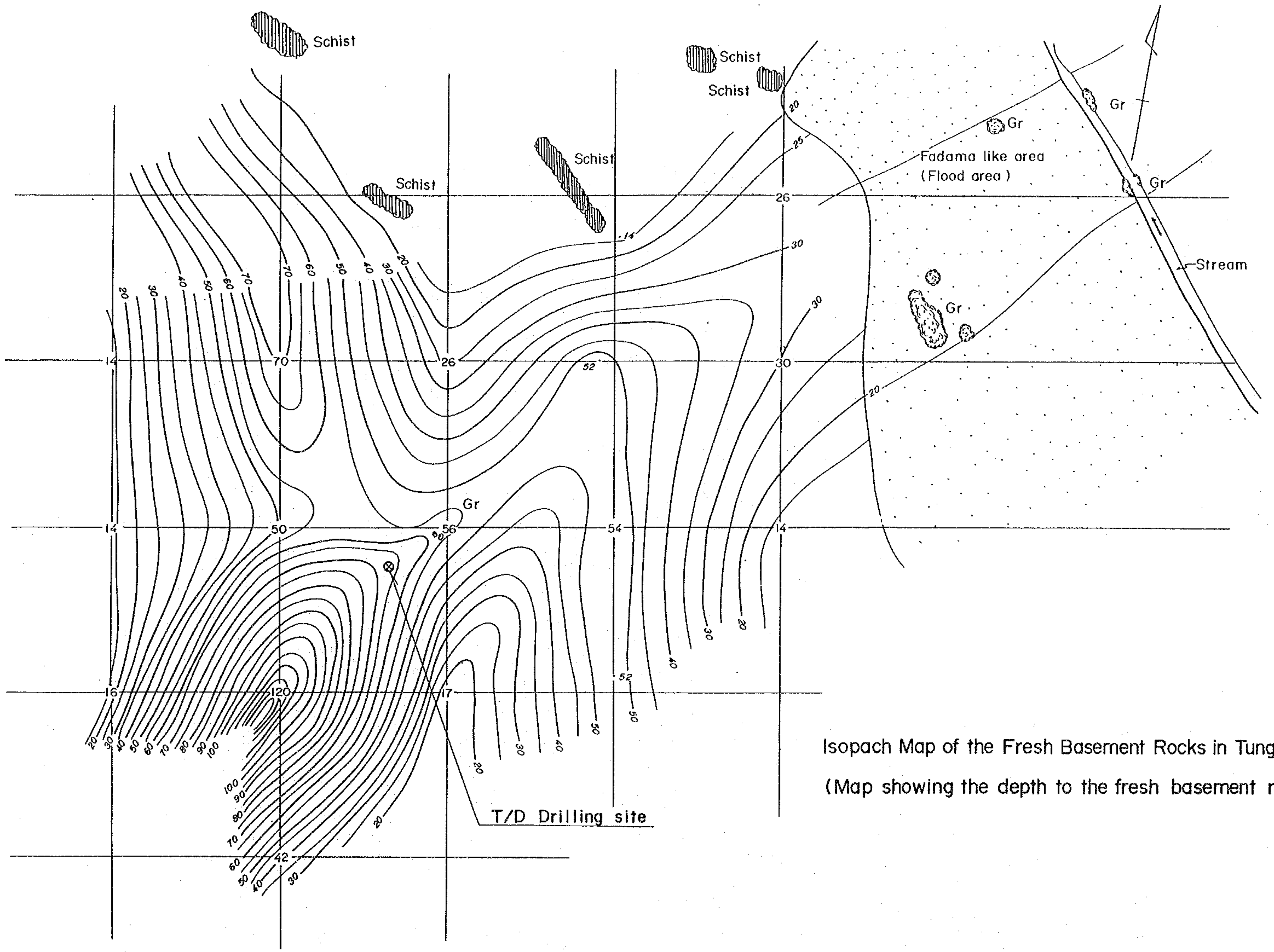
| Borehole No. | Depth(m) | S.W.L.(m) | S.C.(m³/d/m) |
|---|---|---|---|
| NW 3 | 45.0 | 13.11 | 6.51 |
| NW 4 | 49.0 | 12.82 | 1.64 |
| NW 5 | 24.0 | 13.13 | 15.61 |
| NW 6 | 40.0 | 17.30 | 4.63 |
| NW 13 | 30.0 | 13.45 | 7.13 |
| NE 1 | 54.0 | 39.0 | 0.43 |
| NE 2 | 49.0 | 15.63 | 1.44 |
| NE 6 | 49.0 | 30.71 | 3.69 |
| NE 13 | 31.0 | 21.38 | 3.15 |
| NE 14 | 50.0 | 36.75 | 6.41 |
| NE 15 | 52.0 | 29.69 | 2.03 |

S.W.L.: Static Water Level
SC : Specific Capacity

## THE LOCATIONS OF INVESTIGATION AND THE TOPOGRAPHICAL FEATURE

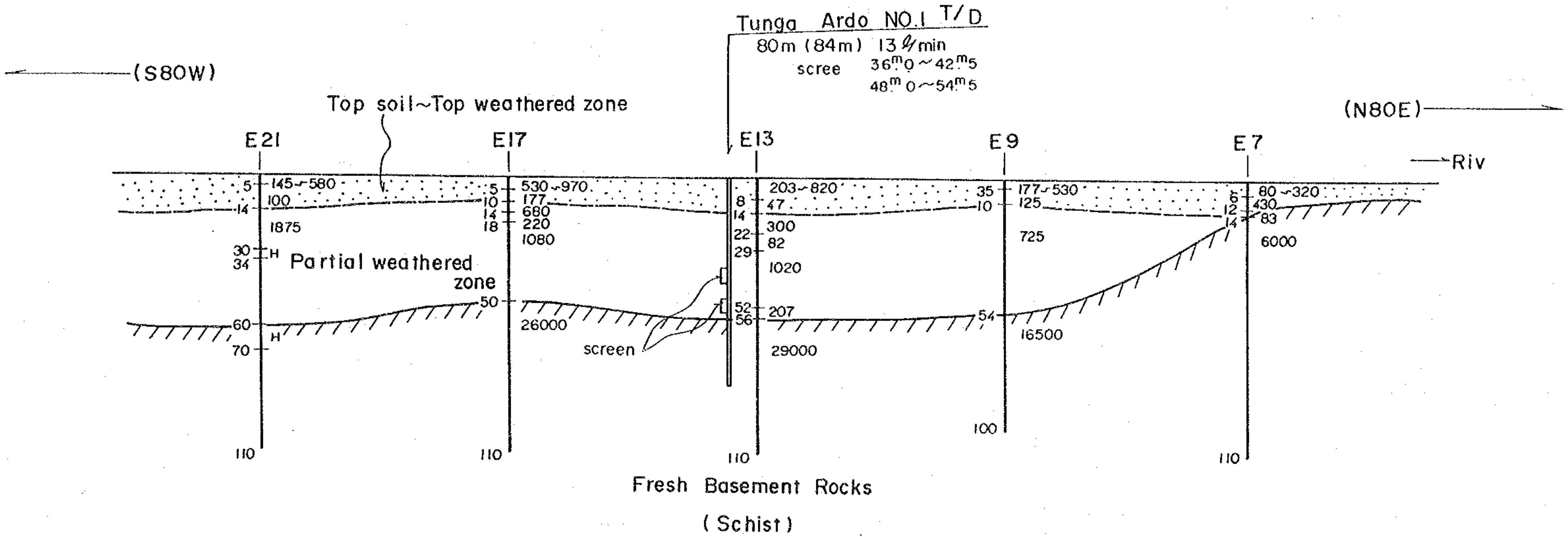
No. I Tunga Ardo

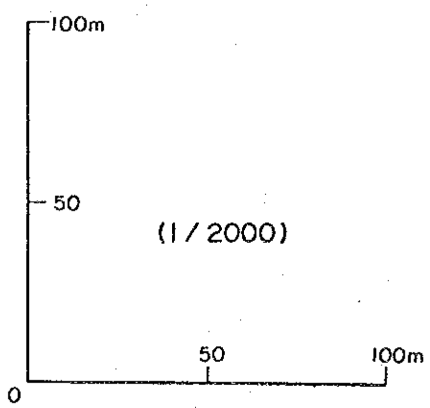





Isopach Map of the Fresh Basement Rocks in Tunga Ardo

(Map showing the depth to the fresh basement rocks)



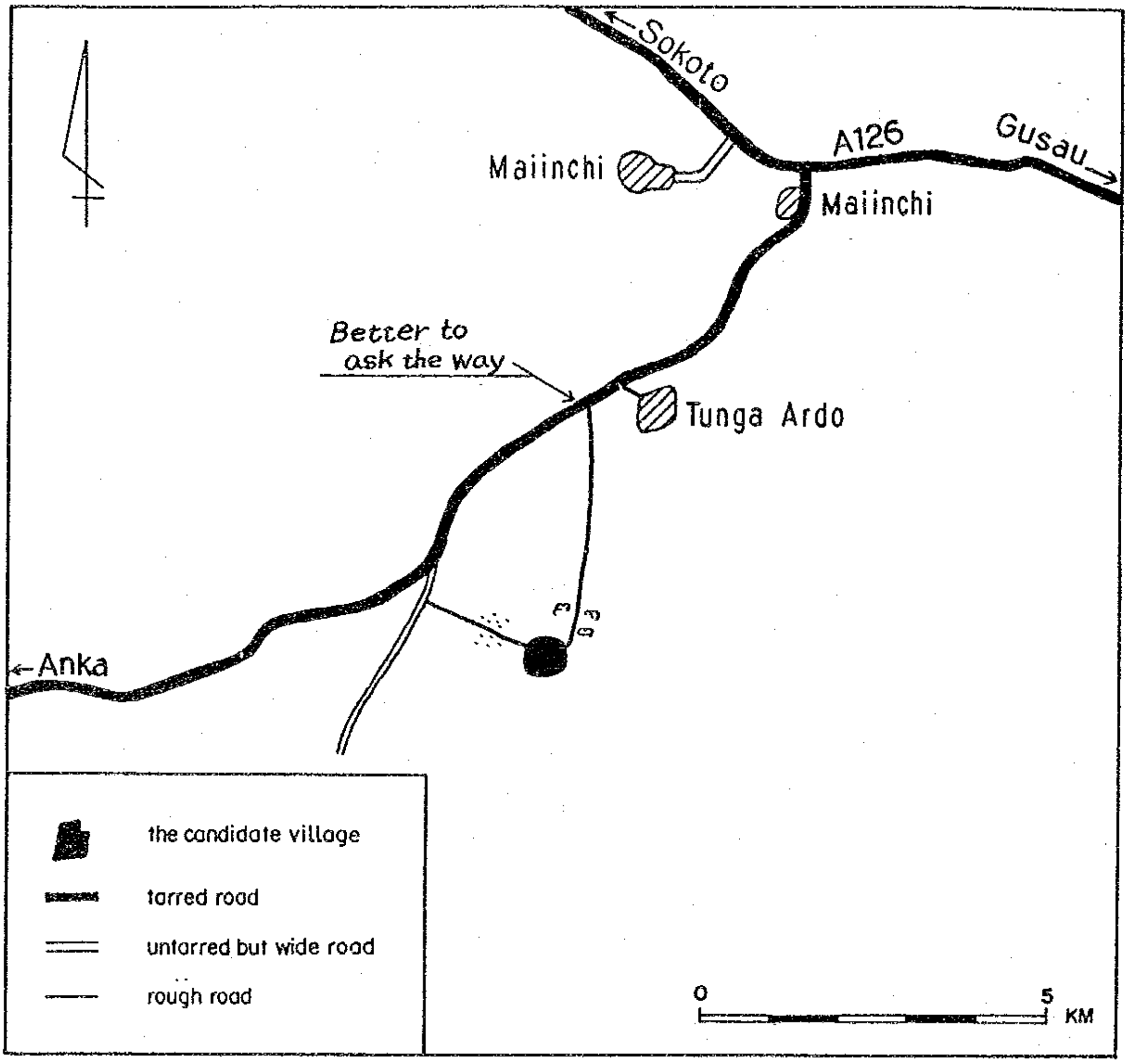




Hydrogeological Section of Tunga Ardo Area

# The Study for Groundwater Development in Sokoto State

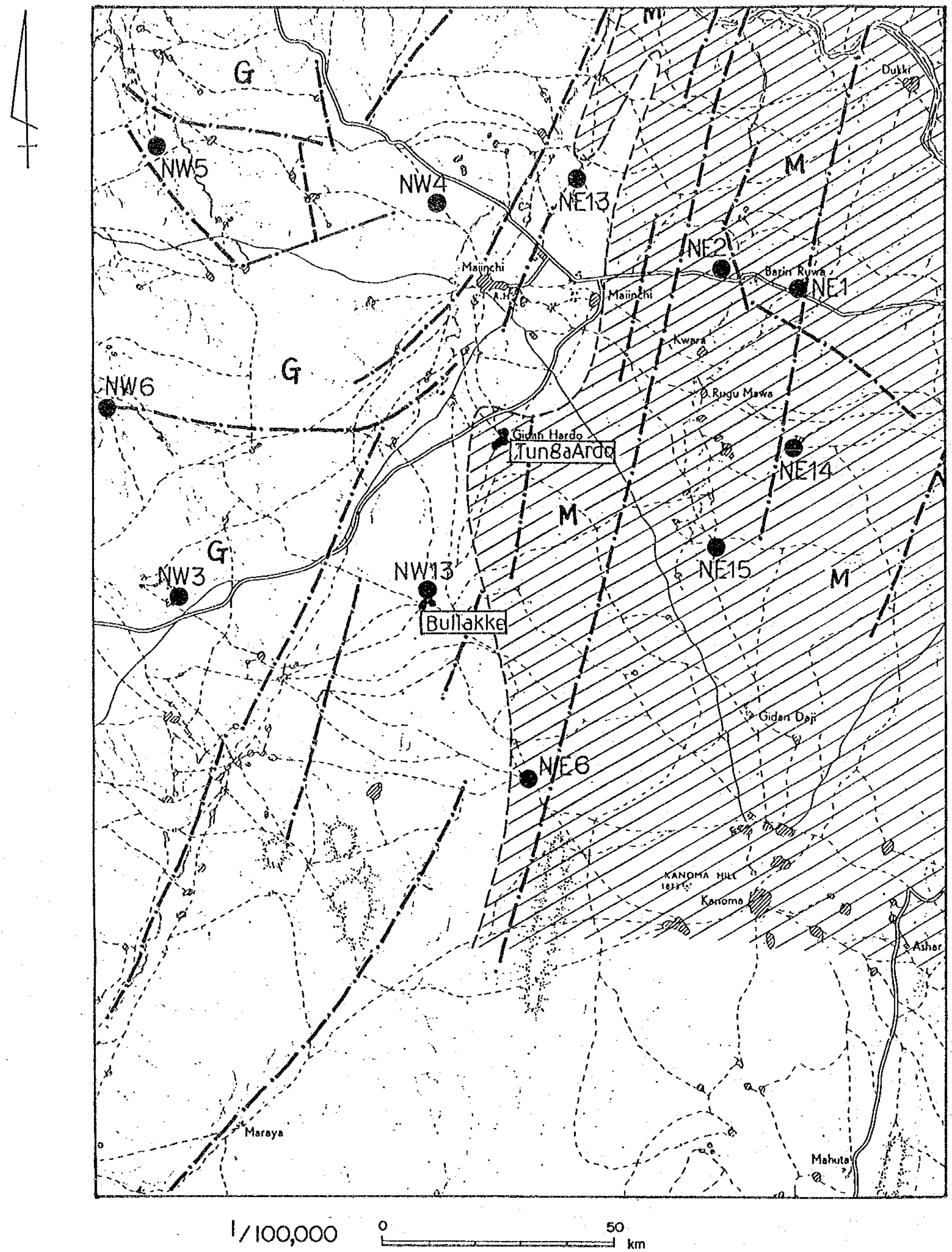
## VILLAGE : Bullakke

Village No. 2




## LOCATION MAP

( 1/100,000 Sheet 53 )




## GEOLOGICAL MAP

### Bullakke

G Older Granite

M Meta-sediments

Lineament

SW 16 Existing Boreholes

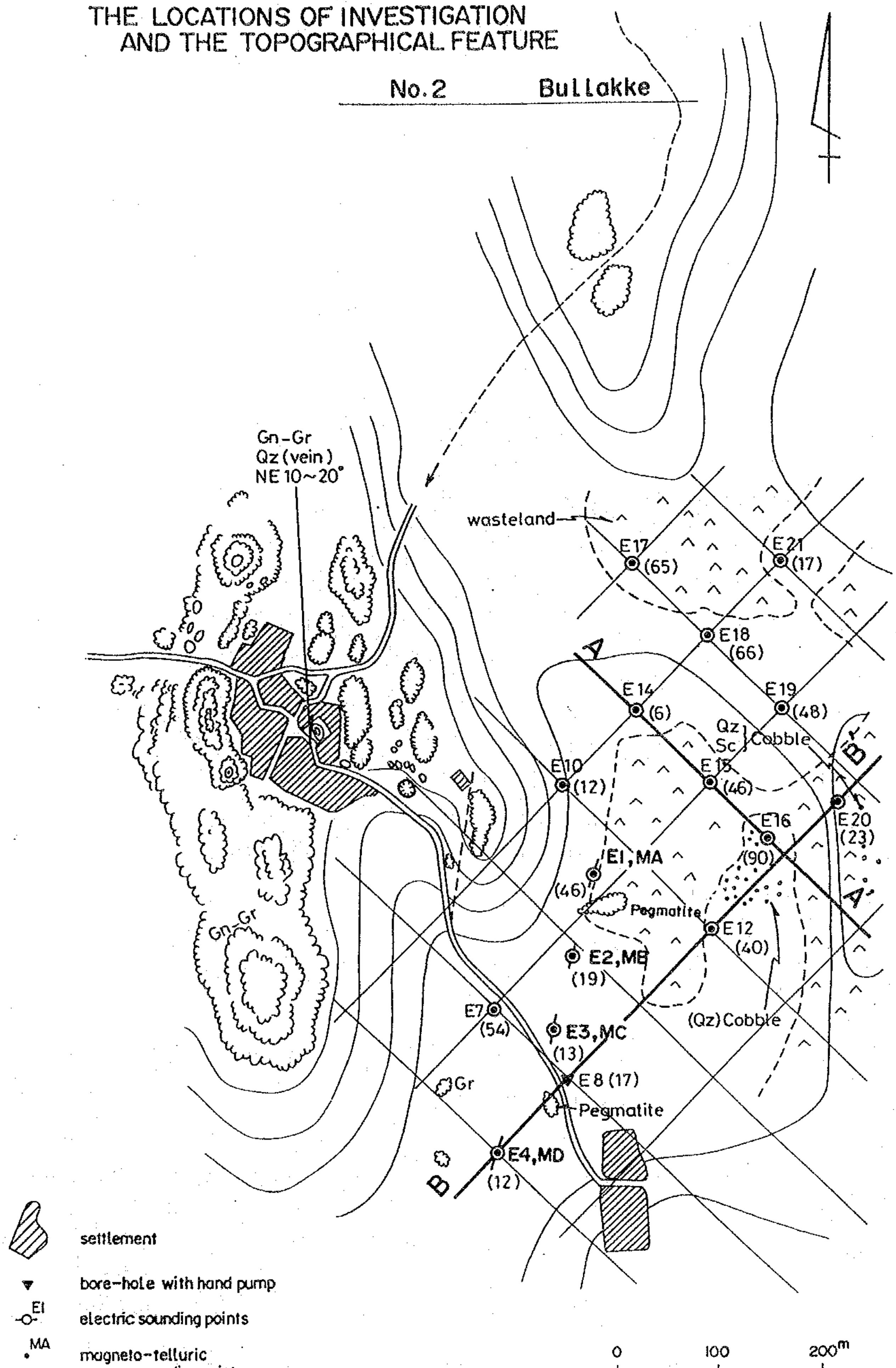
DATA OF EXISTING BOREHOLES

| Borehole No. | Depth(m) | S.W.L.(m) | S.C.(m³/d/m) |
|---|---|---|---|
| NW 3 | 45.0 | 13.11 | 6.51 |
| NW 4 | 49.0 | 12.82 | 1.64 |
| NW 5 | 24.0 | 13.13 | 15.61 |
| NW 6 | 40.0 | 17.30 | 4.63 |
| NW 13 | 30.0 | 13.45 | 7.13 |
| NE 1 | 54.0 | 39.0 | 0.43 |
| NE 2 | 49.0 | 15.63 | 1.44 |
| NE 6 | 49.0 | 30.71 | 3.69 |
| NE 13 | 31.0 | 21.38 | 3.15 |
| NE 14 | 50.0 | 36.75 | 6.41 |
| NE 15 | 52.0 | 29.69 | 2.03 |

S.W.L.: Static Water Level
SC : Specific Capacity

THE LOCATIONS OF INVESTIGATION
AND THE TOPOGRAPHICAL FEATURE

No.2 Bullakke



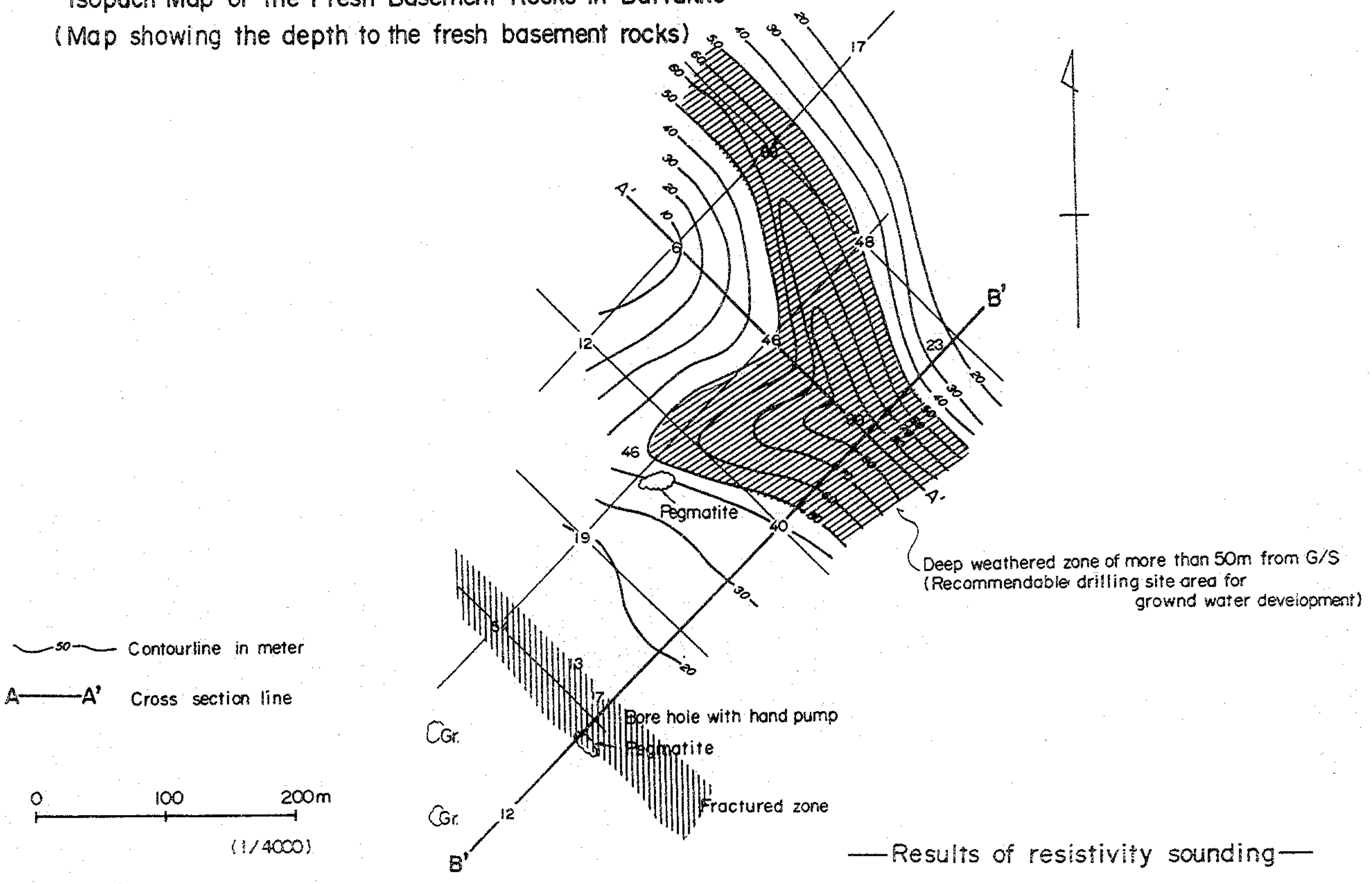

settlement

bore-hole with hand pump

electric sounding points

magneto-telluric sounding points

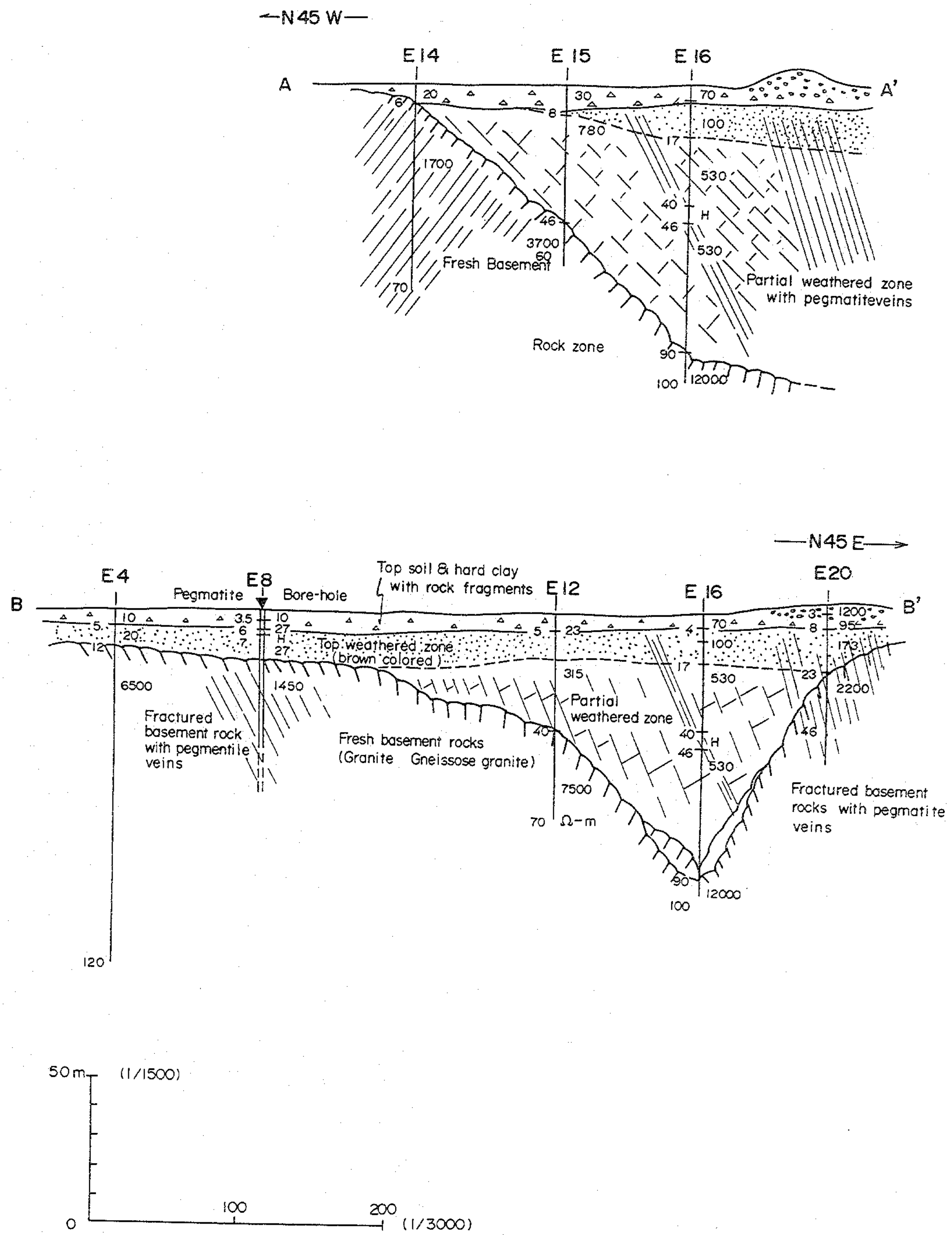
## Isopach Map of the Fresh Basement Rocks in Bullakke
(Map showing the depth to the fresh basement rocks)




—Results of resistivity sounding—

## Hydrogeological Section of Bullakke Area

(Map showing resistivity profile & estimated lithologic distribution)

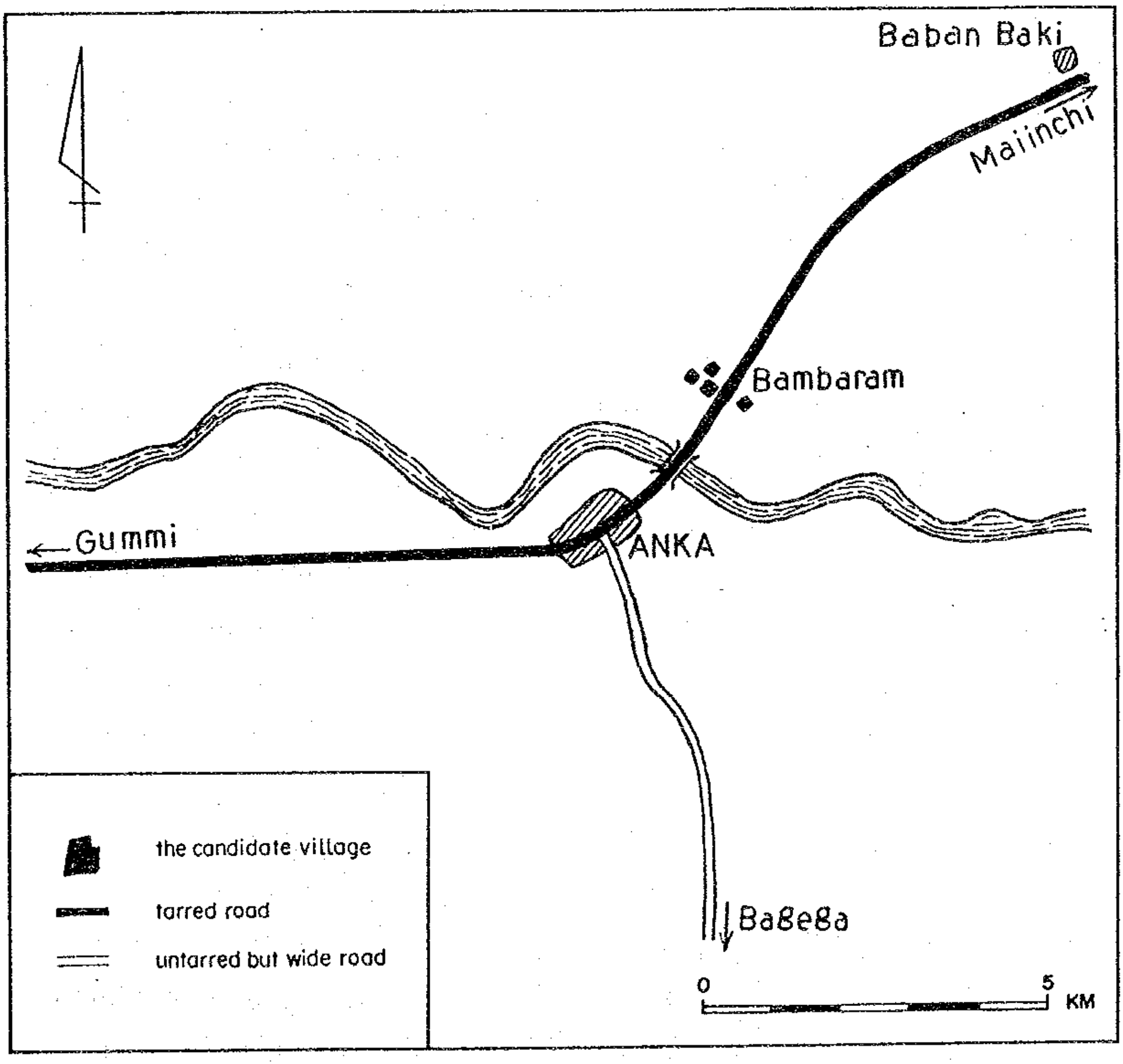



—Results of resistivity sounding—

# The Study for Groundwater Development in Sokoto State

**VILLAGE : Bambaram**

Village No. 3



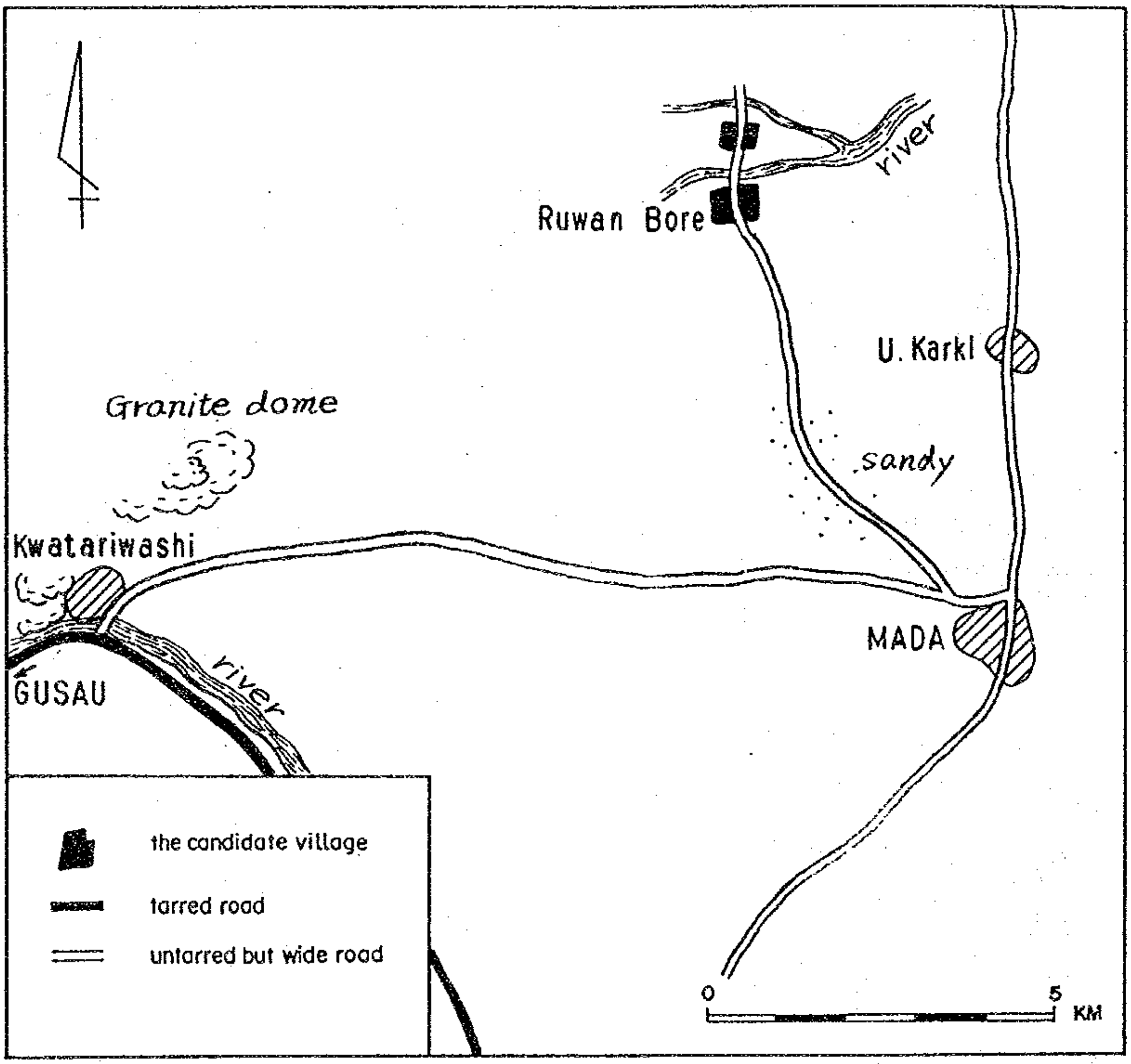

## LOCATION MAP

( 1/100,000 Sheet 52 )

# The Study for Groundwater Development in Sokoto State

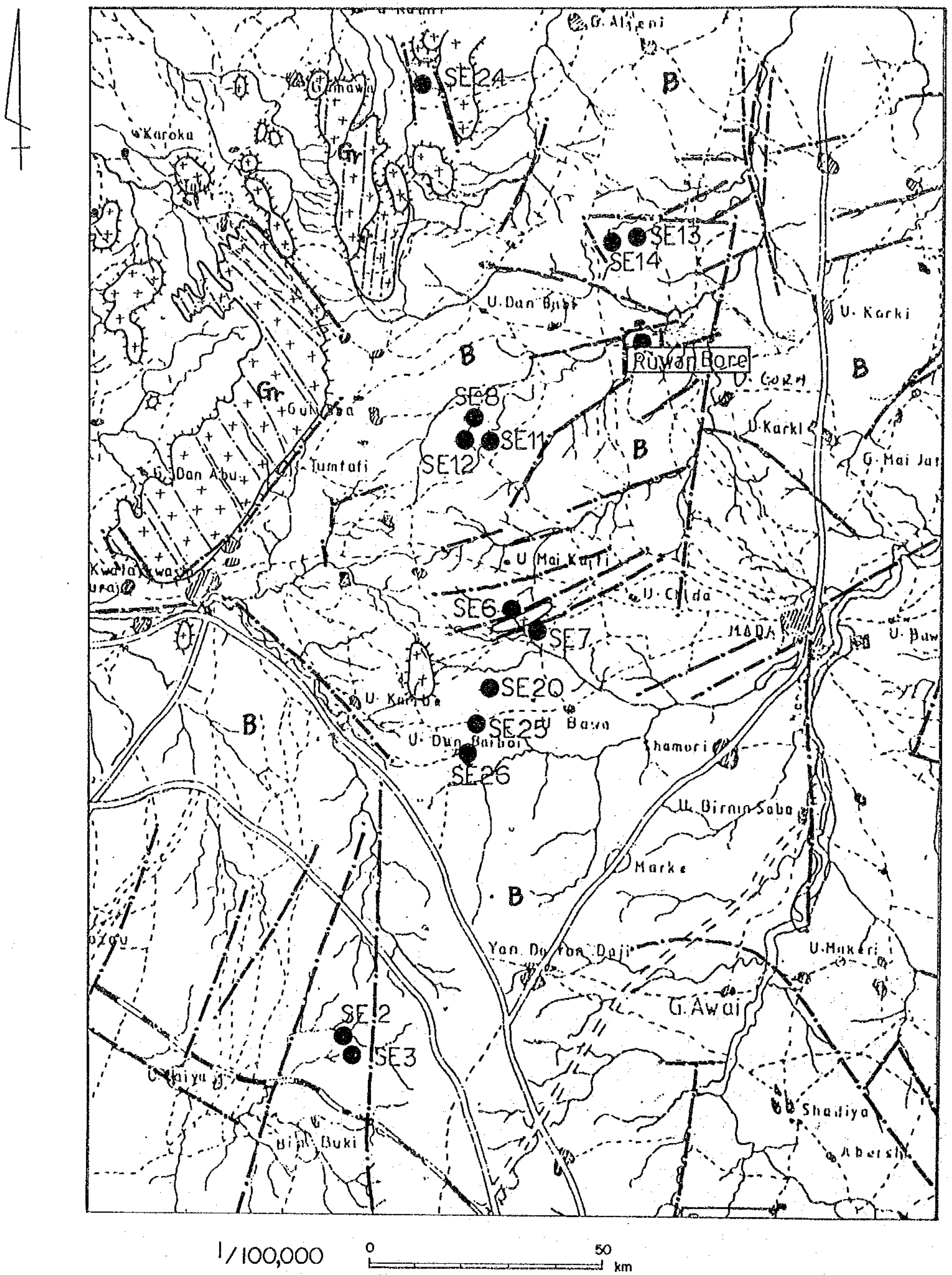
| VILLAGE : Ruwan Bore |
|---|

Village No. 4




## LOCATION MAP

( 1/100,000 Sheet 54 )




# GEOLOGICAL MAP

## Ruwan Bore

B Basement Complex

G Granite Dome

Lineament (Fault)

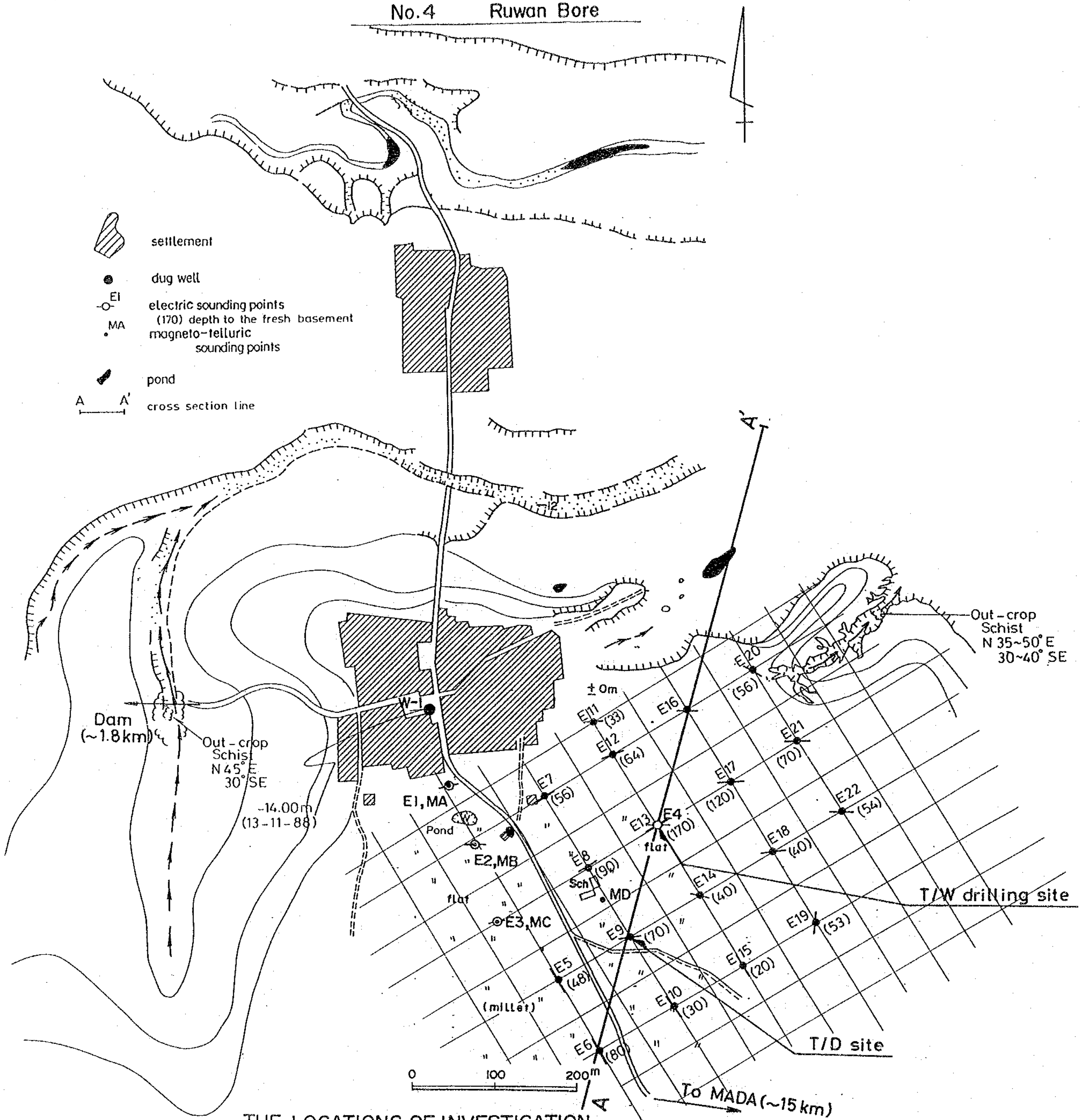
Lineation (Foliation)

● SW 16 Existing Boreholes

DATA OF EXISTING BOREHOLES

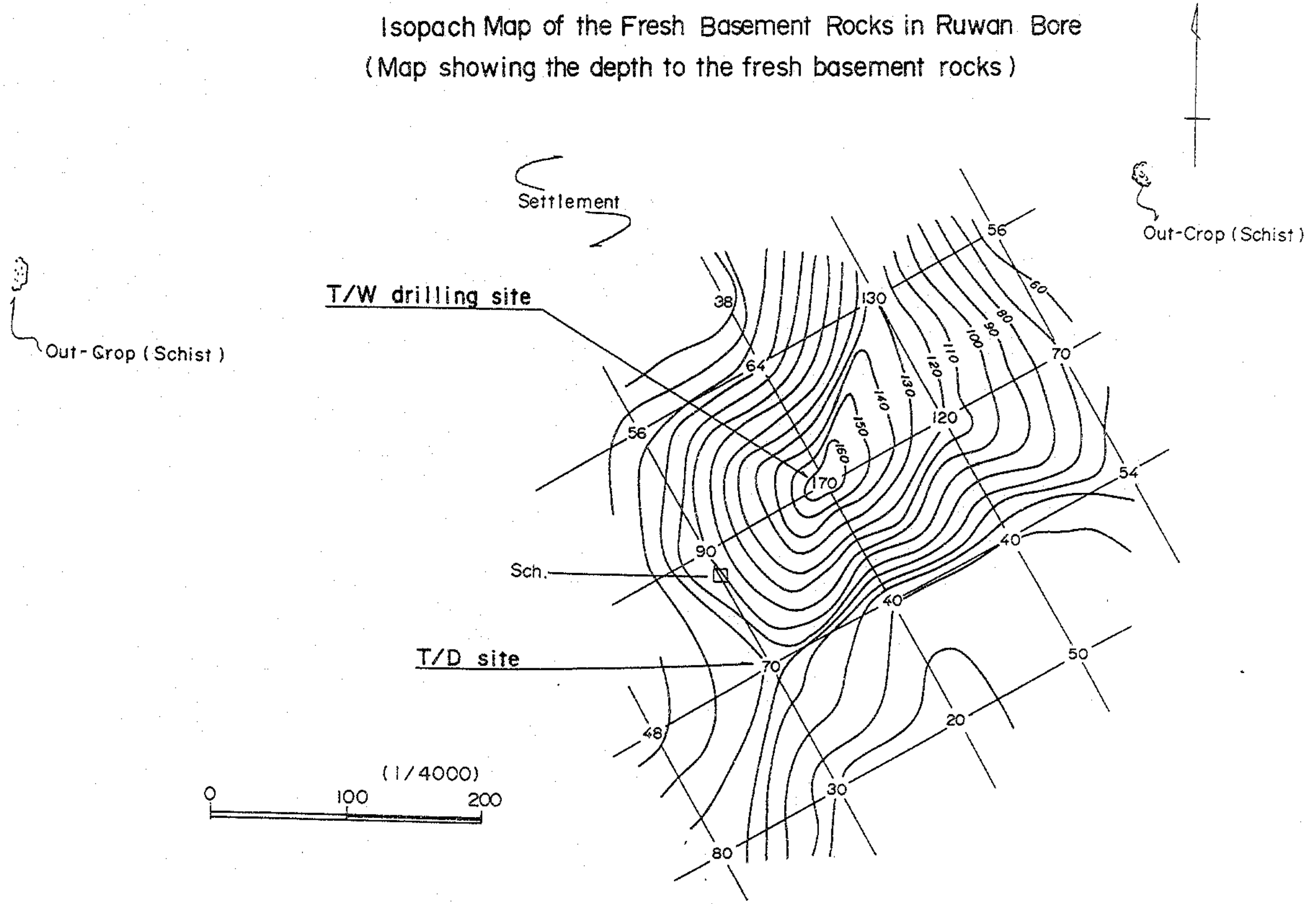
| Borehole No. | Depth(m) | S.W.L.(m) | S.C.(m³/d/m) |
|---|---|---|---|
| SE 2 | 49.0 | 19.15 | 2.42 |
| SE 3 | 37.0 | 17.07 | 1.04 |
| SE 6 | 37.0 | 13.97 | 1.15 |
| SE 7 | 31.0 | 15.24 | 0.69 |
| SE 8 | 49.0 | 19.95 | 0.74 |
| SE 11 | 25.0 | 15.93 | 5.52 |
| SE 12 | 31.0 | 16.81 | 3.02 |
| SE 13 | 23.0 | 9.19 | 31.76 |
| SE 14 | 25.0 | 9.19 | 2.25 |
| SE 20 | 33.0 | 15.96 | 5.81 |
| SE 24 | 49.0 | 11.91 | 1.57 |
| SE 25 | 33.0 | 20.28 | 6.83 |
| SE 26 | 31.0 | 15.85 | 14.26 |

S.W.L. : Static Water Level
SC : Specific Capacity

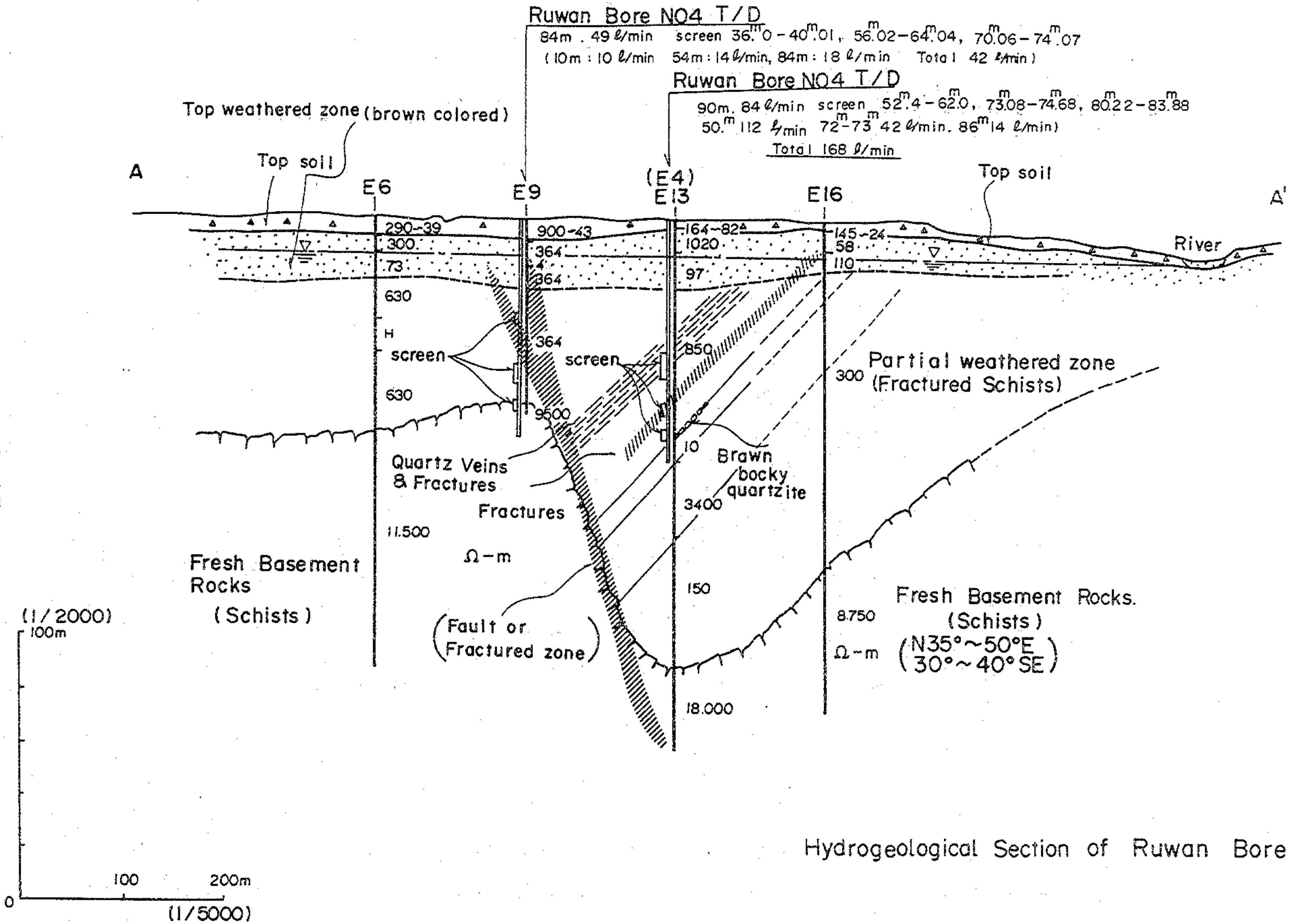



THE LOCATIONS OF INVESTIGATION
AND THE TOPOGRAPHICAL FEATURE

Isopach Map of the Fresh Basement Rocks in Ruwan Bore
(Map showing the depth to the fresh basement rocks)




— Result of resitivity Sounding —

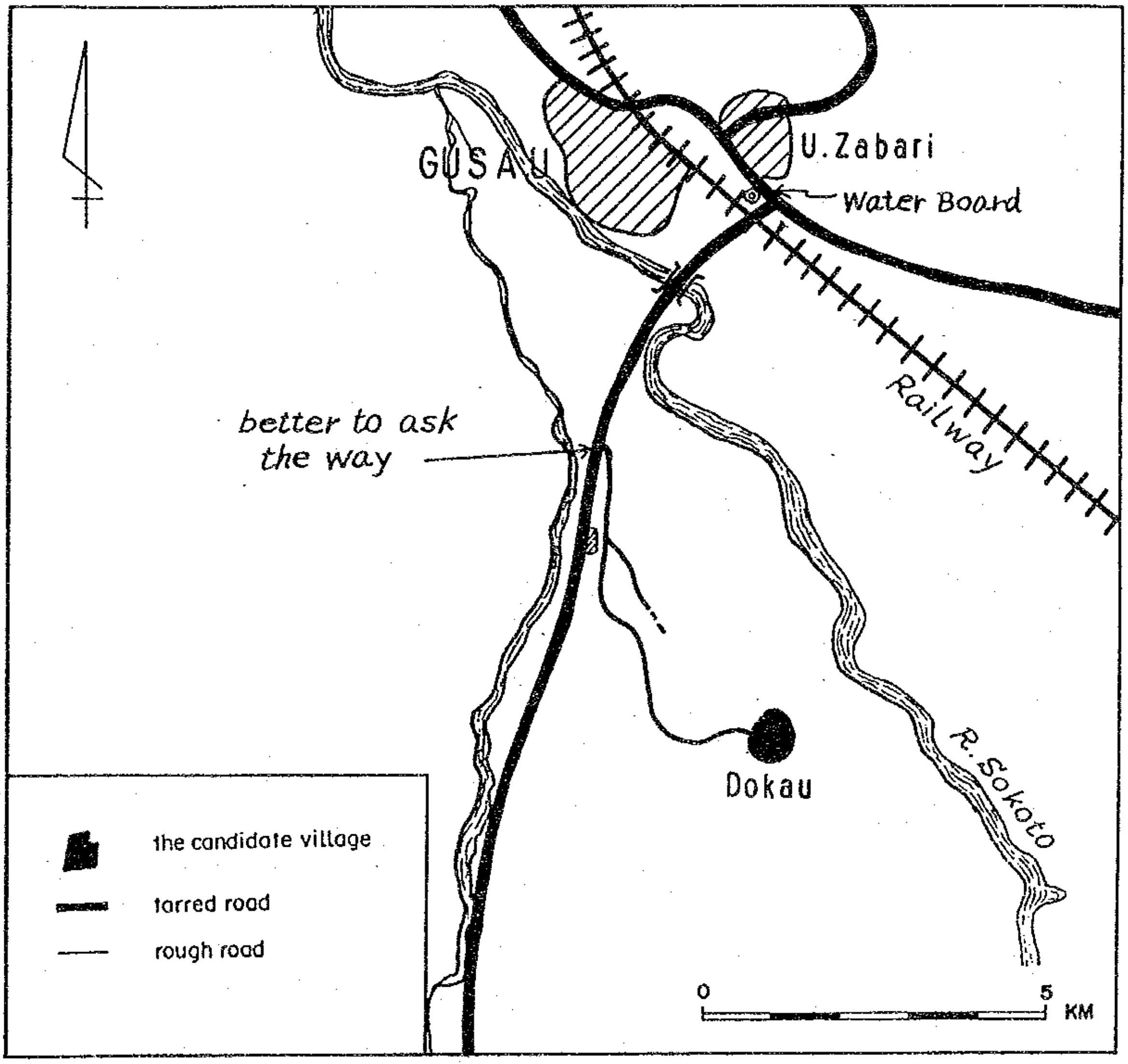



Hydrogeological Section of Ruwan Bore Area

# The Study for Groundwater Development in Sokoto State

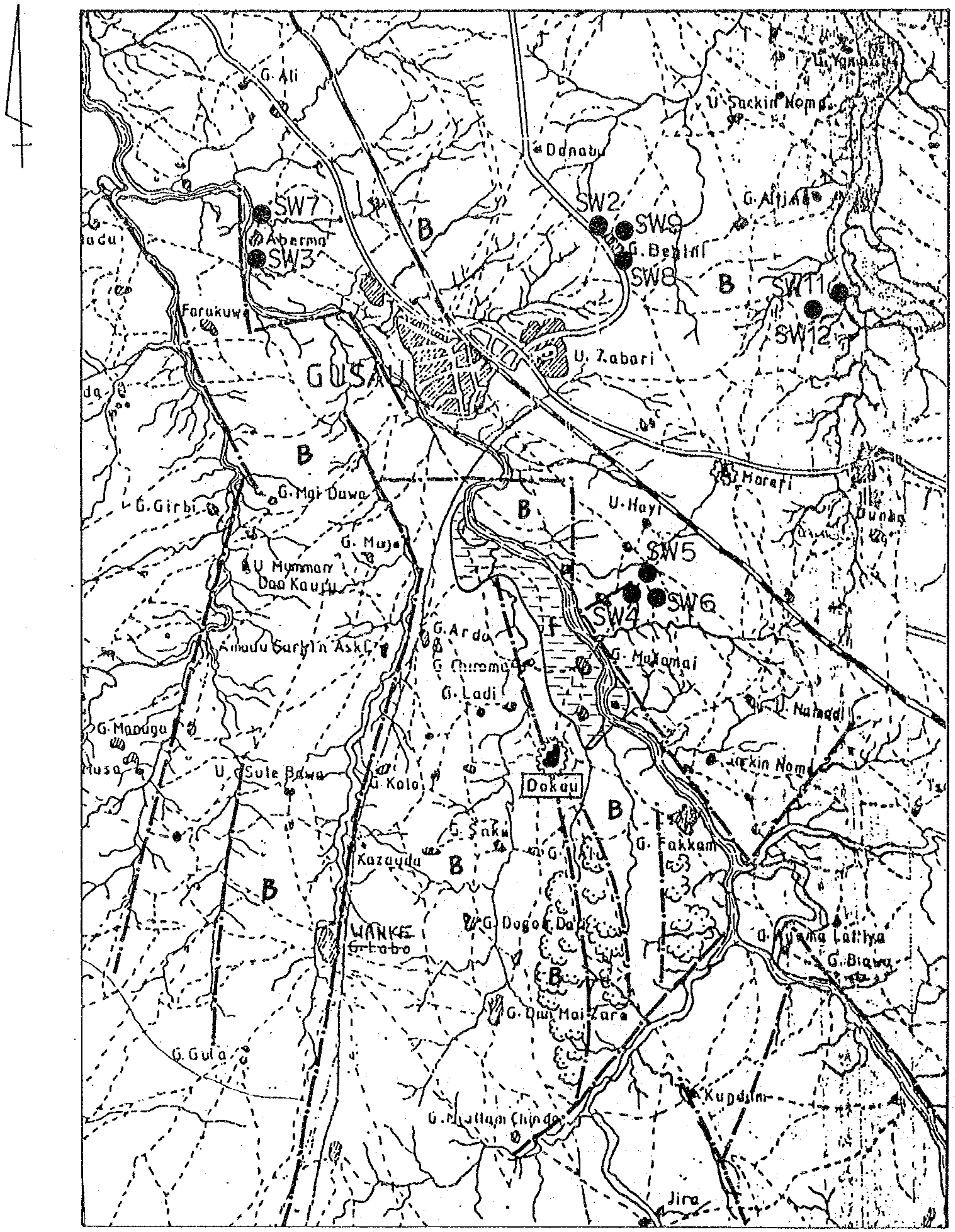
| VILLAGE : Dokau |
|---|

Village No. 5




## LOCATION MAP

( 1/100,000 Sheet 54 )




1/100,000 0 50 km

# GEOLOGICAL MAP

## Dokau

River

Fadama

Lineament

B Basement Complex

SW 16 Existing Boreholes

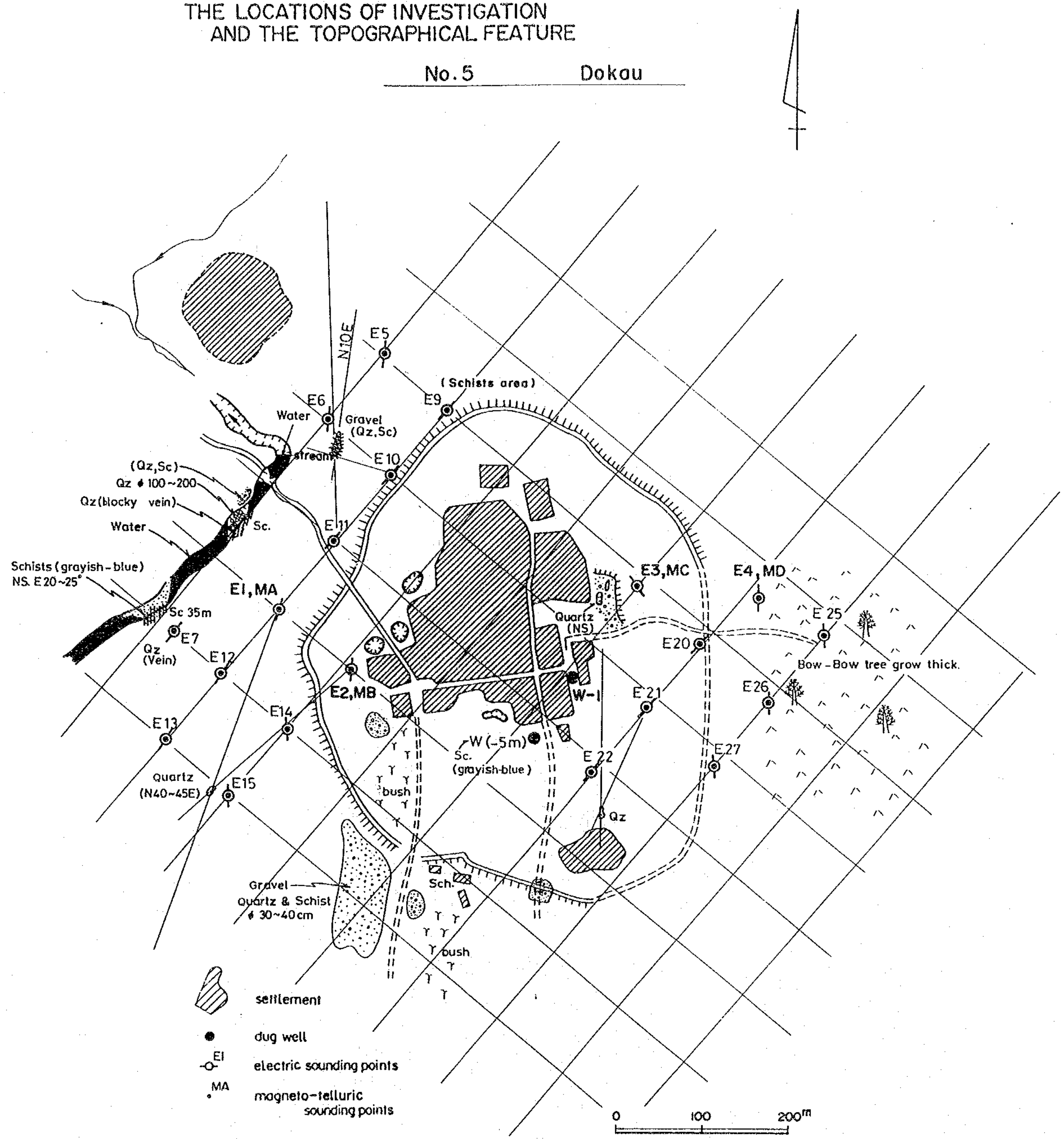
DATA OF EXISTING BOREHOLES

| Borehole No. | Depth(m) | S.W.L.(m) | S.C.($m^3$/d/m) |
|---|---|---|---|
| SW 2 | 17.0 | 2.76 | 0.23 |
| SW 3 | 61.0 | 15.50 | 5.84 |
| SW 4 | 49.0 | 12.06 | 0.51 |
| SW 5 | 49.0 | 8.17 | 0.69 |
| SW 6 | 37.0 | 11.35 | 0.85 |
| SW 7 | 31.0 | 8.85 | 1.17 |
| SW 8 | 18.0 | 3.47 | 5.93 |
| SW 9 | 31.0 | 3.12 | 2.14 |
| SW 11 | 31.0 | 3.63 | 2.17 |
| SW 12 | 37.0 | 3.85 | 1.18 |

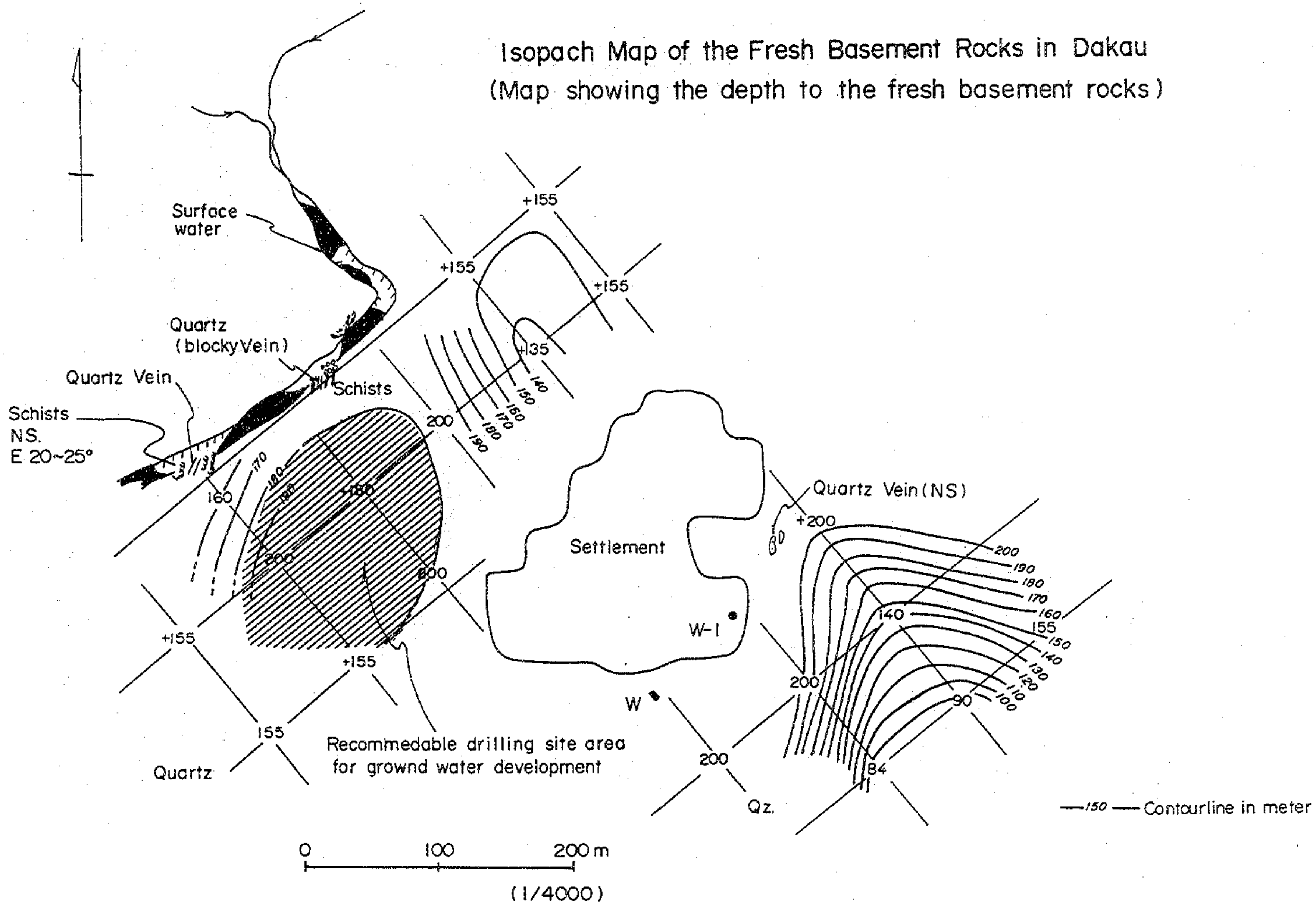
S.W.L.: Static Water Level
SC : Specific Capacity

# THE LOCATIONS OF INVESTIGATION AND THE TOPOGRAPHICAL FEATURE

No. 5 Dokau



## Isopach Map of the Fresh Basement Rocks in Dakau
(Map showing the depth to the fresh basement rocks)

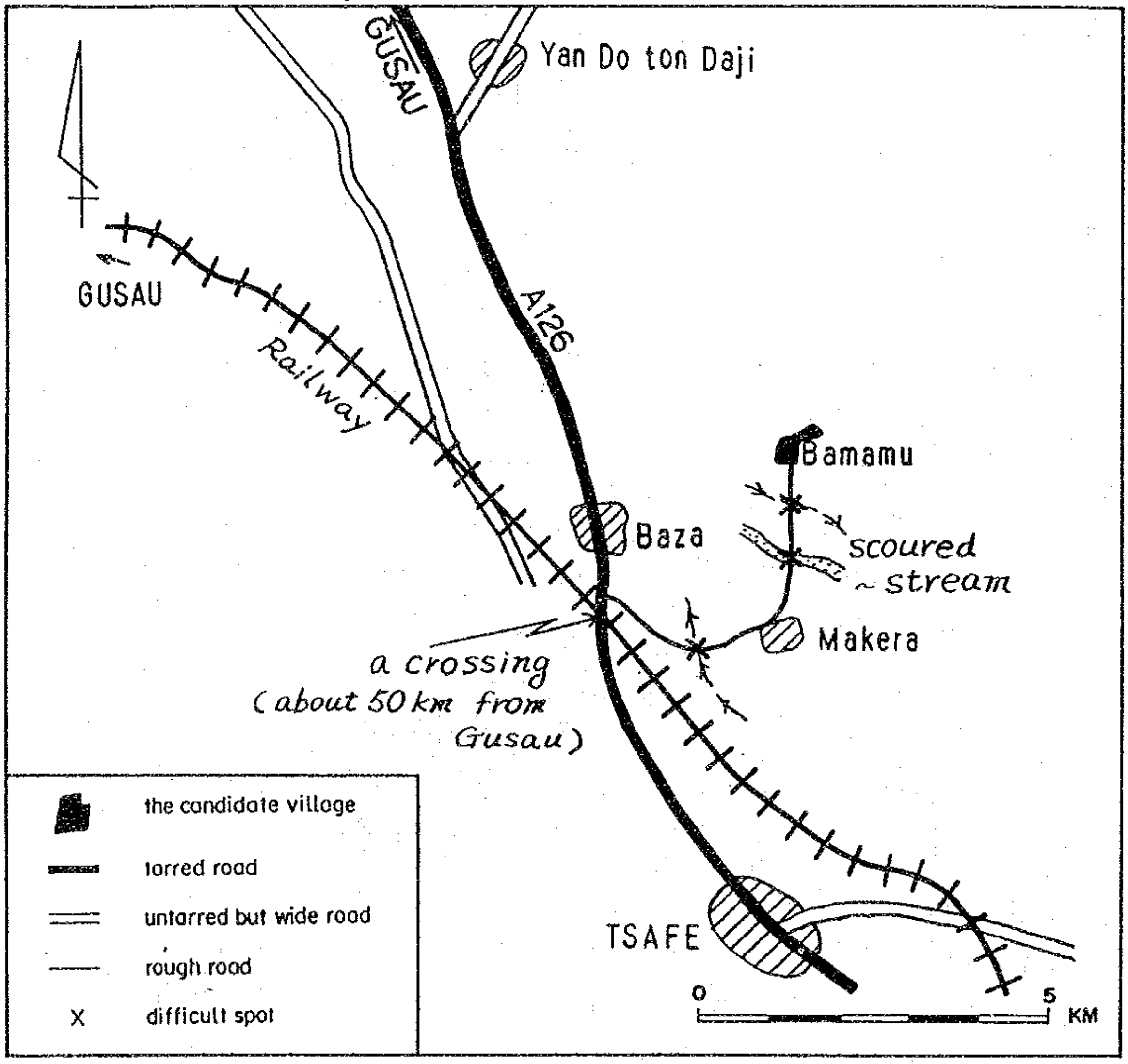



— Result of resitivity Sounding —

## The Study for Groundwater Development in Sokoto State

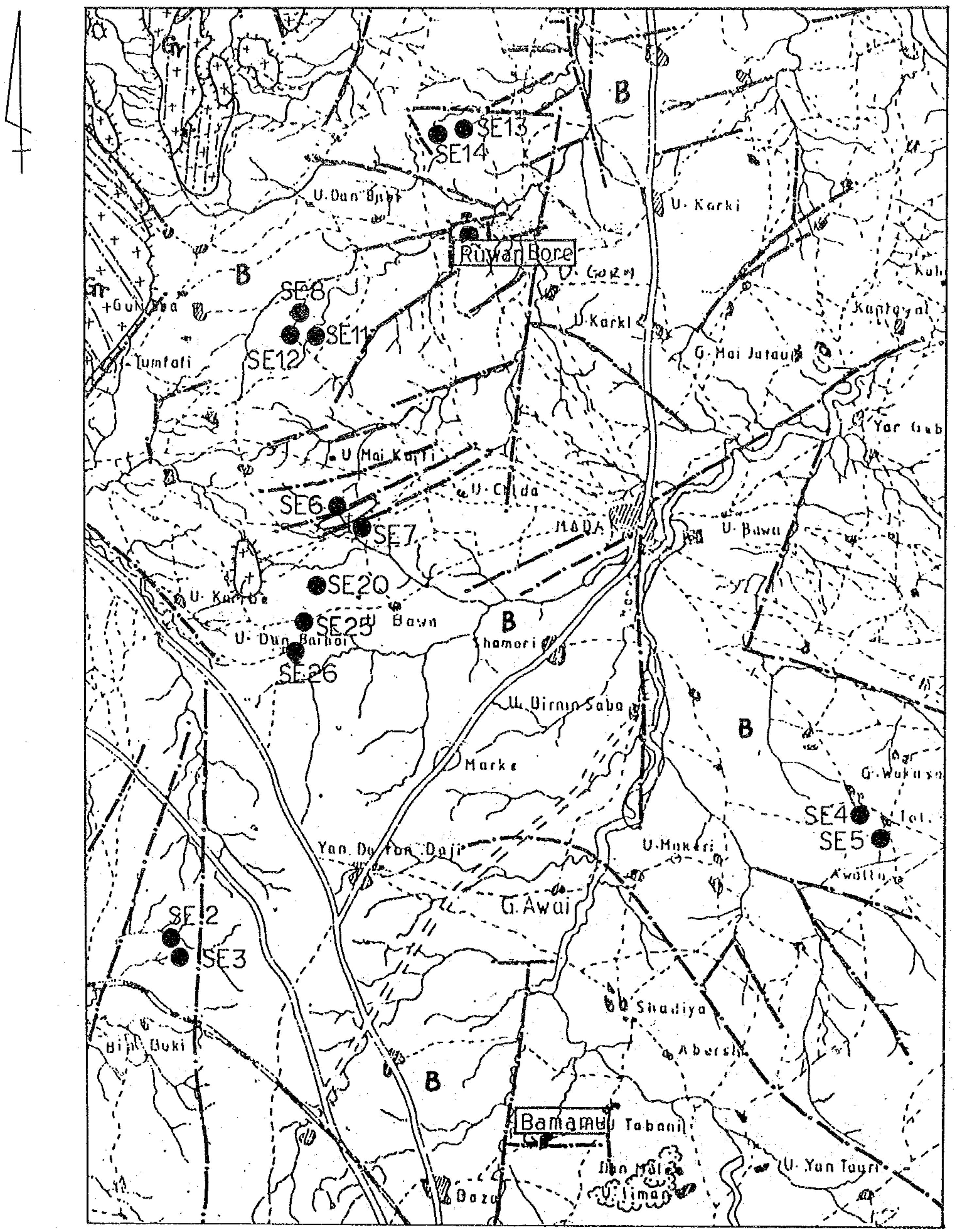
VILLAGE : Barnamu

Village No. 6




## LOCATION MAP

( 1/100,000 Sheet 54 )




1/100,000   0 — 50 km

# GEOLOGICAL MAP

## Bamamu

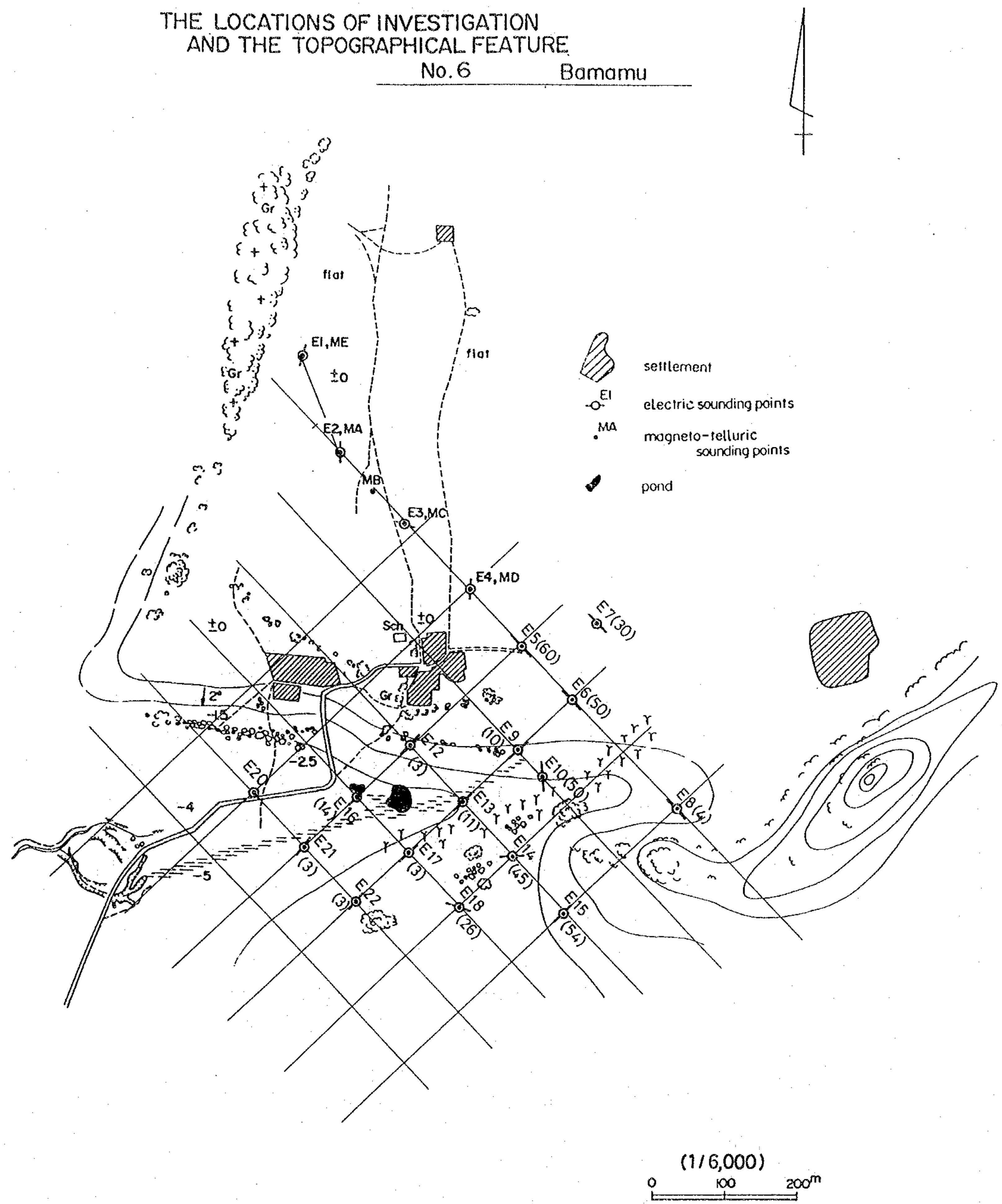
- B — Basement Complex
- +G+ — Granite Dome
- Lineament (Fault)
- Lineation (Foliation)
- ● SW16 — Existing Boreholes

DATA OF EXISTING BOREHOLES

| Borehole No. | Depth(m) | S.W.L.(m) | S.C.(m³/d/m) |
|---|---|---|---|
| SE 2 | 49.0 | 19.15 | 2.42 |
| SE 3 | 37.0 | 17.07 | 1.04 |
| SE 4 | 28.0 | 5.78 | 6.70 |
| SE 5 | 22.0 | 8.86 | 11.76 |
| SE 6 | 37.0 | 13.97 | 1.15 |
| SE 7 | 31.0 | 15.24 | 0.69 |
| SE 20 | 33.0 | 15.96 | 5.81 |
| SE 25 | 33.0 | 20.28 | 6.83 |
| SE 26 | 31.0 | 15.85 | 14.26 |

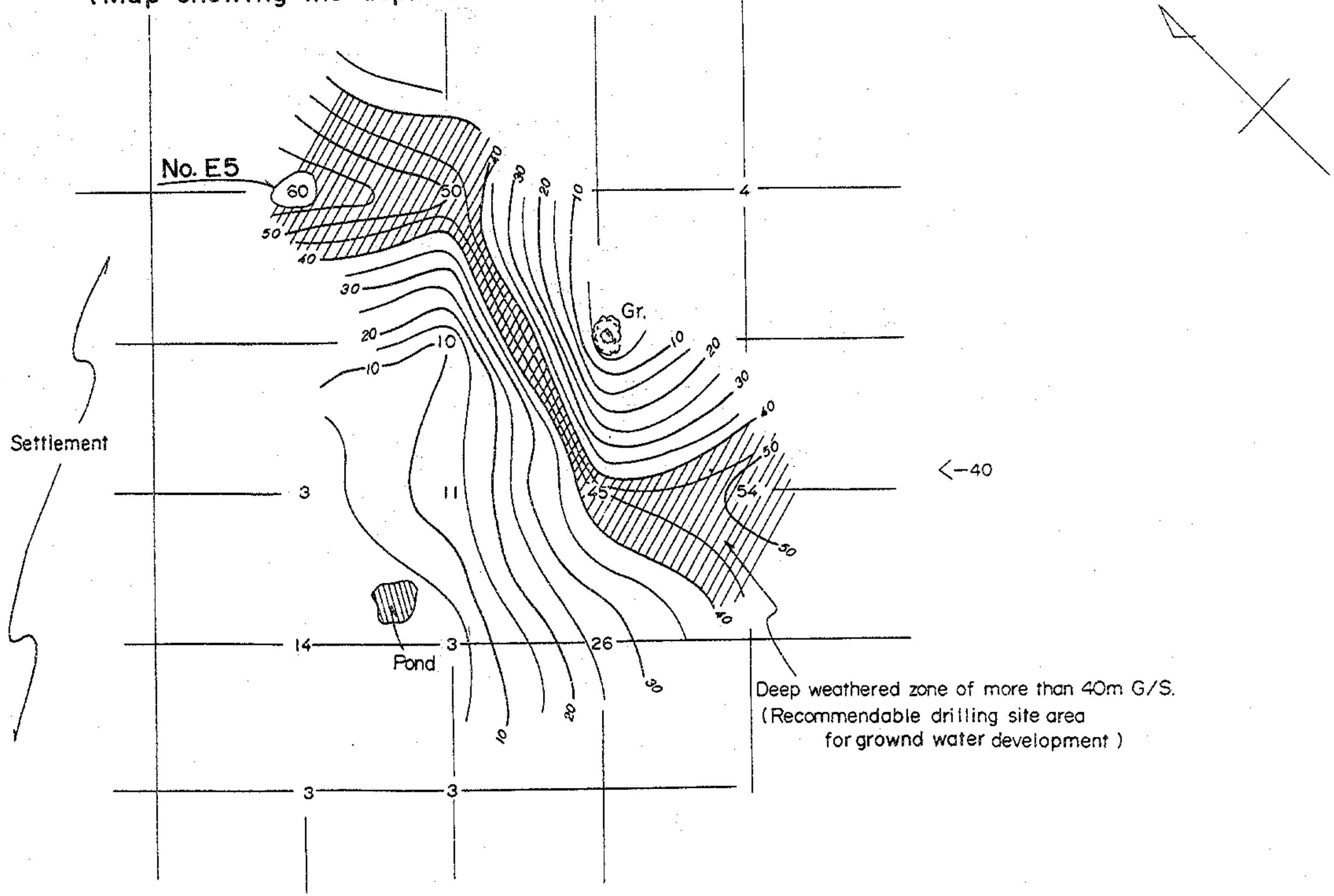
S.W.L.: Static Water Level
S.C : Specific Capacity

THE LOCATIONS OF INVESTIGATION
AND THE TOPOGRAPHICAL FEATURE
No.6 Bamamu



Isopach Map of the Fresh Basement Rocks in Bamamu (No.6)

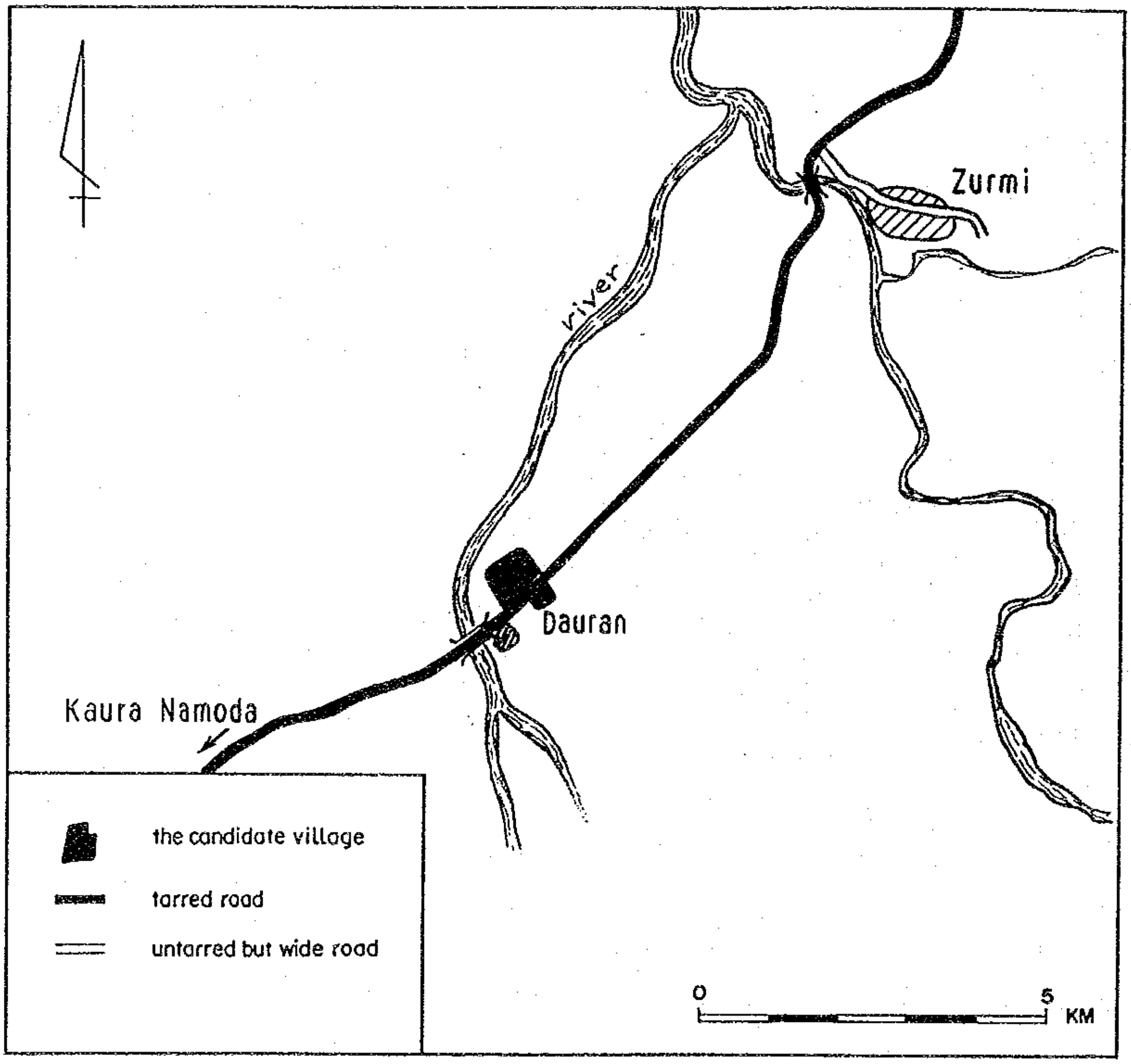
(Map showing the depth to the fresh basement rocks)



# The Study for Groundwater Development in Sokoto State

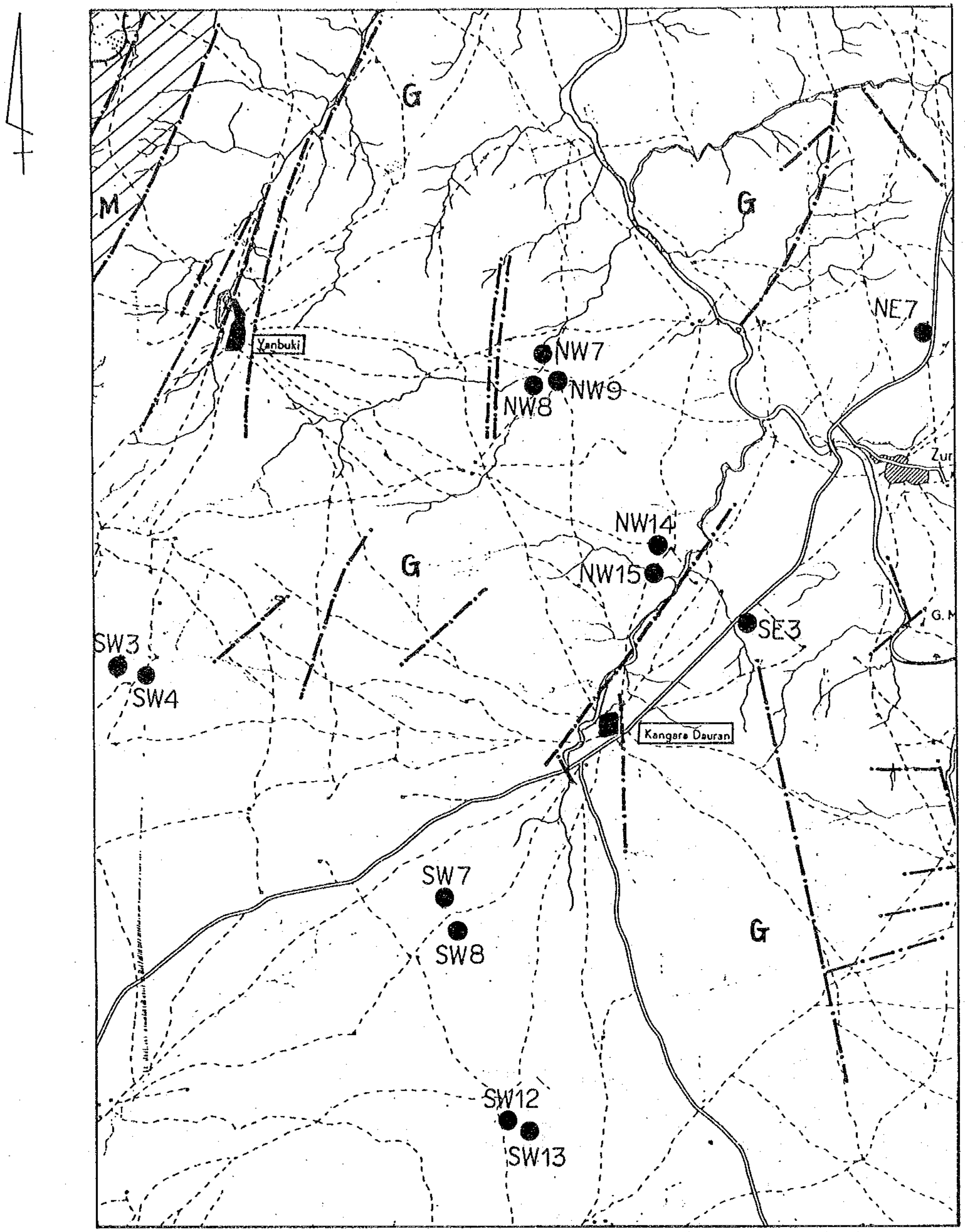
VILLAGE : Dauran

Village No. 7




## LOCATION MAP

( 1/100,000 Sheet 32 )




1/100,000 0 50 km

## GEOLOGICAL MAP

### Dauran

Lineament

G Older Granite

M Meta-sediments

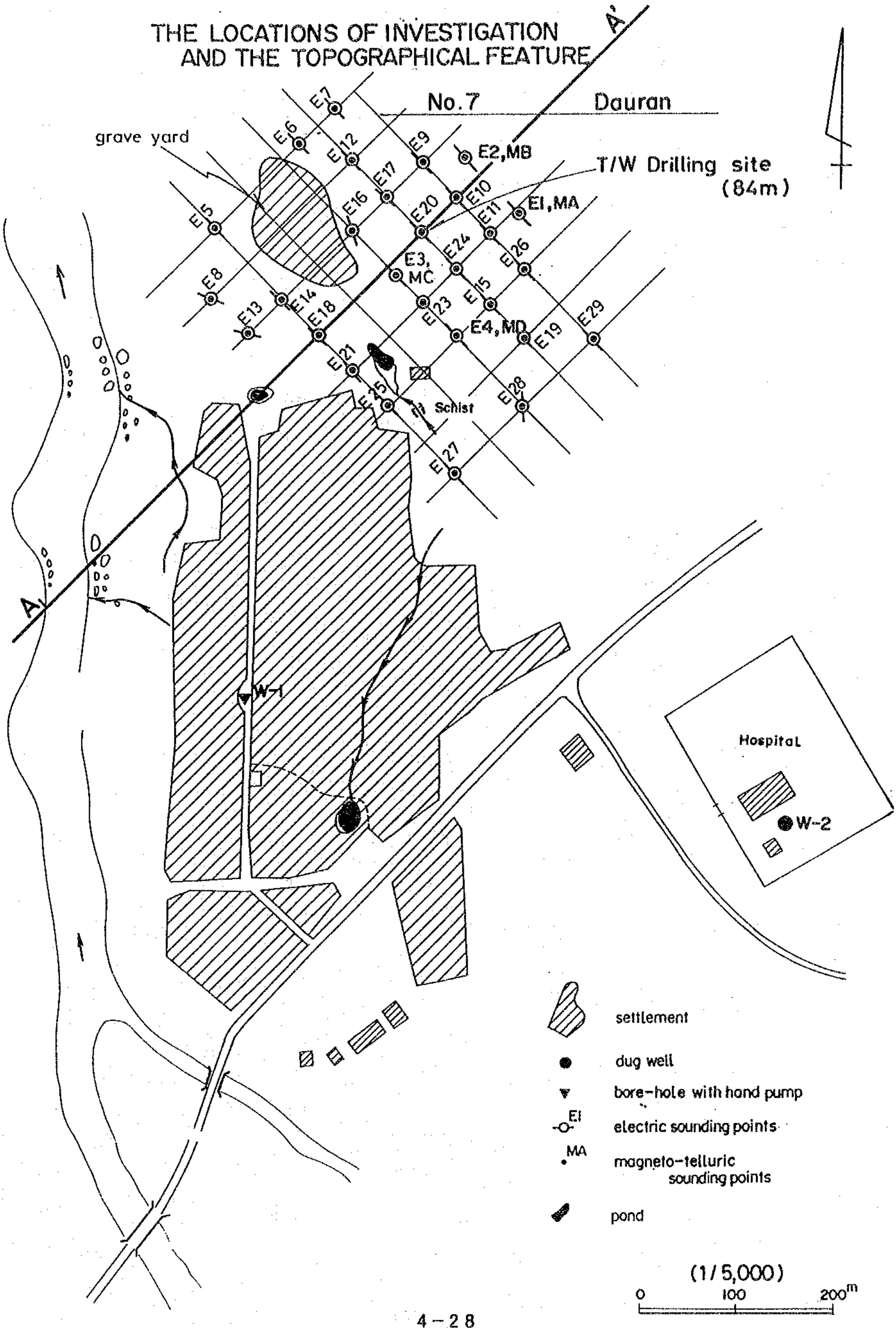
SW 16 Existing Boreholes

DATA OF EXISTING BOREHOLES

| Borehole No. | Depth (m) | S.W.L. (m) | S.C. ($m^3$/d/m) |
|---|---|---|---|
| NW 7 | 25.0 | 12.60 | 216.00 |
| NW 8 | 37.0 | 13.63 | 1.19 |
| NW 9 | 37.0 | 14.04 | 59.59 |
| NW 14 | 25.0 | 10.51 | 17.44 |
| NW 15 | 24.0 | 11.85 | 5.19 |
| SW 3 | 41.0 | 24.99 | 3.97 |
| SW 4 | 34.0 | 24.33 | 55.74 |
| SW 7 | 73.0 | 38.75 | 54.74 |
| SW 8 | 73.0 | 38.26 | 4.50 |
| SW 12 | 61.0 | 30.25 | 3.32 |
| SW 13 | 55.0 | 33.79 | 34.36 |
| NE 7 | 43.0 | 26.97 | 4.96 |
| SE 3 | 34.0 | 15.15 | 10.77 |

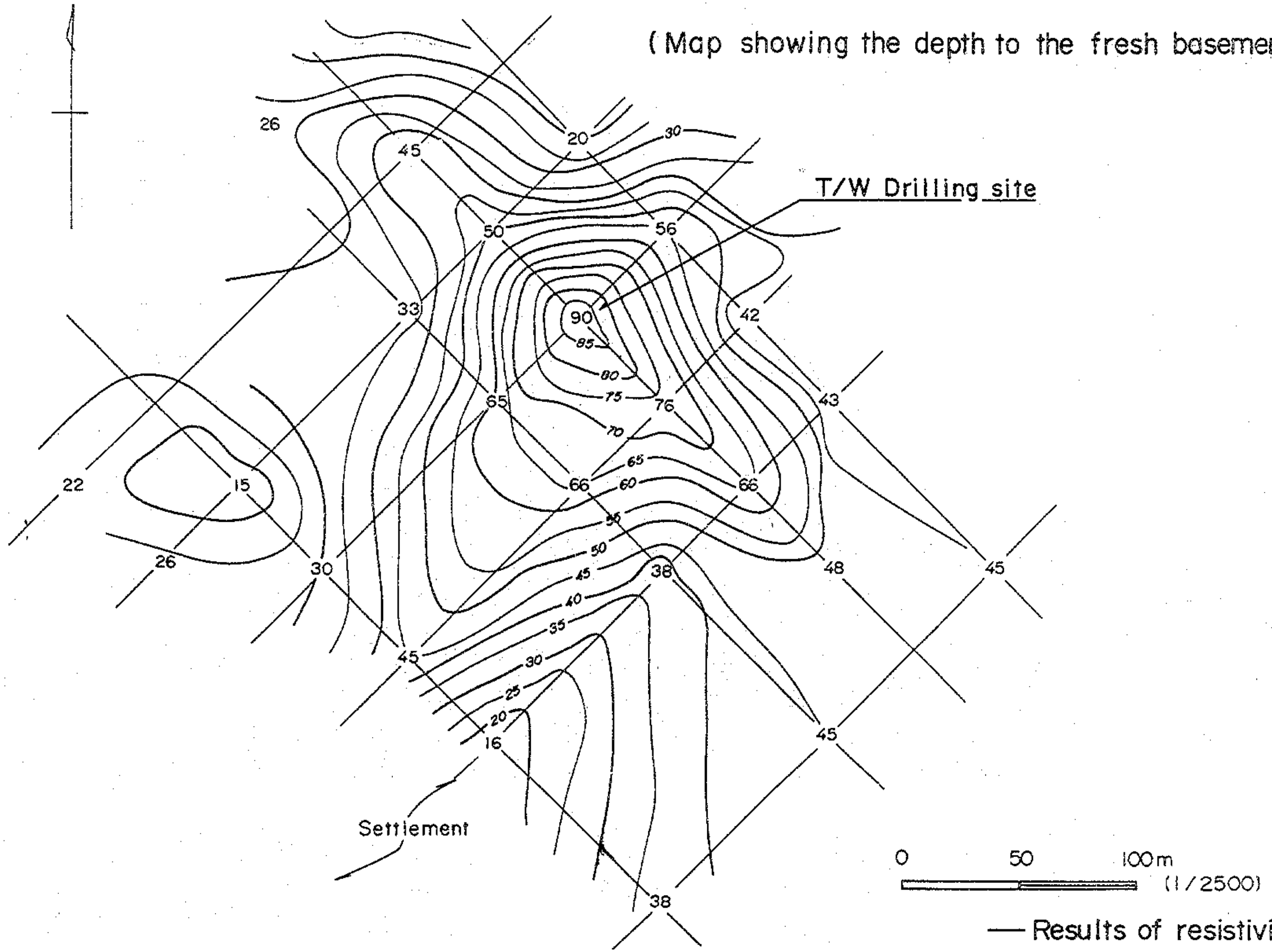
S.W.L.: Static Water Level
SC : Specific Capacity

# THE LOCATIONS OF INVESTIGATION AND THE TOPOGRAPHICAL FEATURE

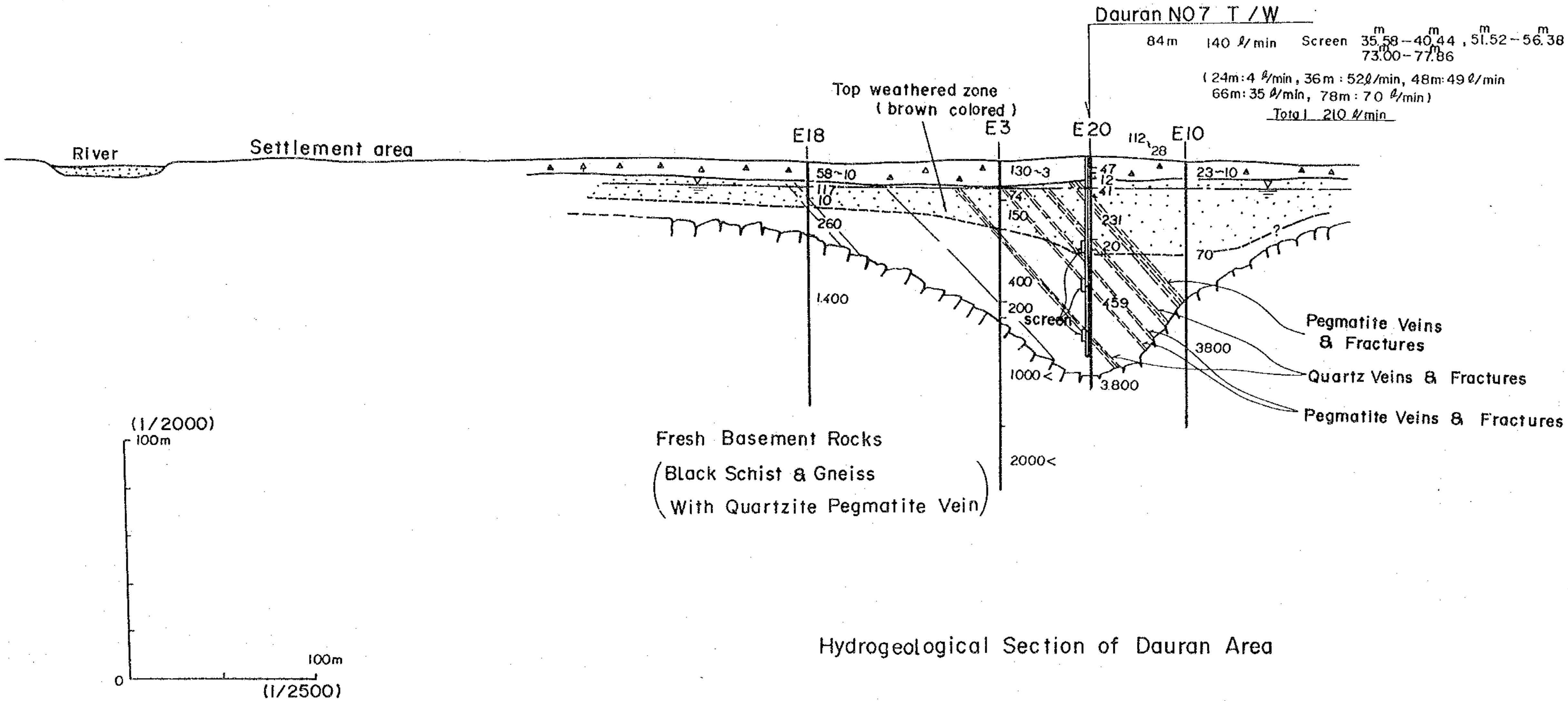


Isopach Map of the Fresh Basement Rocks in Dauran

(Map showing the depth to the fresh basement rocks)




— Results of resistivity sounding —

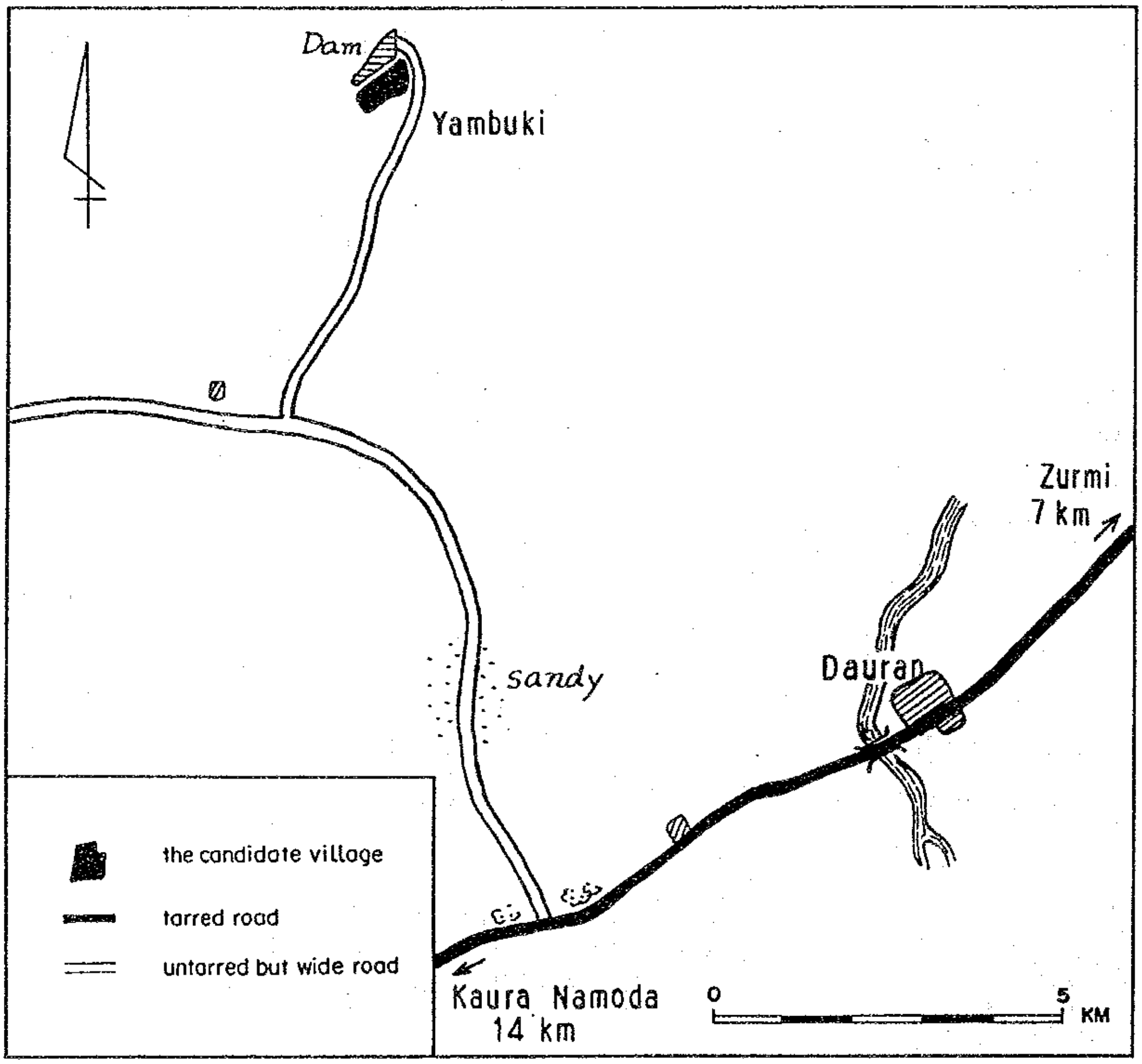



Hydrogeological Section of Dauran Area

# The Study for Groundwater Development in Sokoto State

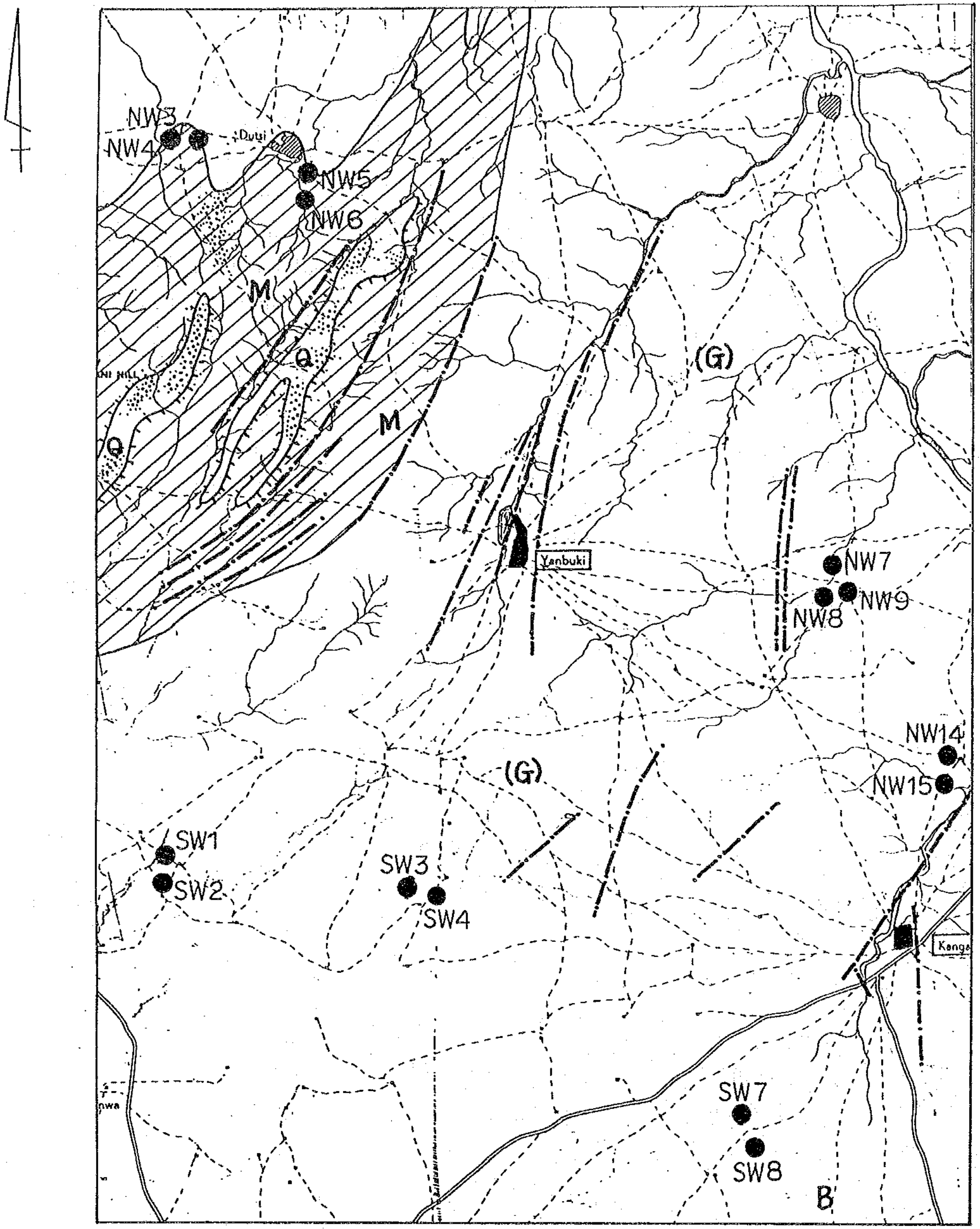
VILLAGE : Yambuki

Village No. 8




## LOCATION MAP

( 1/100,000 Sheet 32 )




# GEOLOGICAL MAP

## Yambuki

Escarpment

Lineament

M Meta-sediments

Q Quartzite

G Older Granite

● SW 16 Existing Boreholes

DATA OF EXISTING BOREHOLES

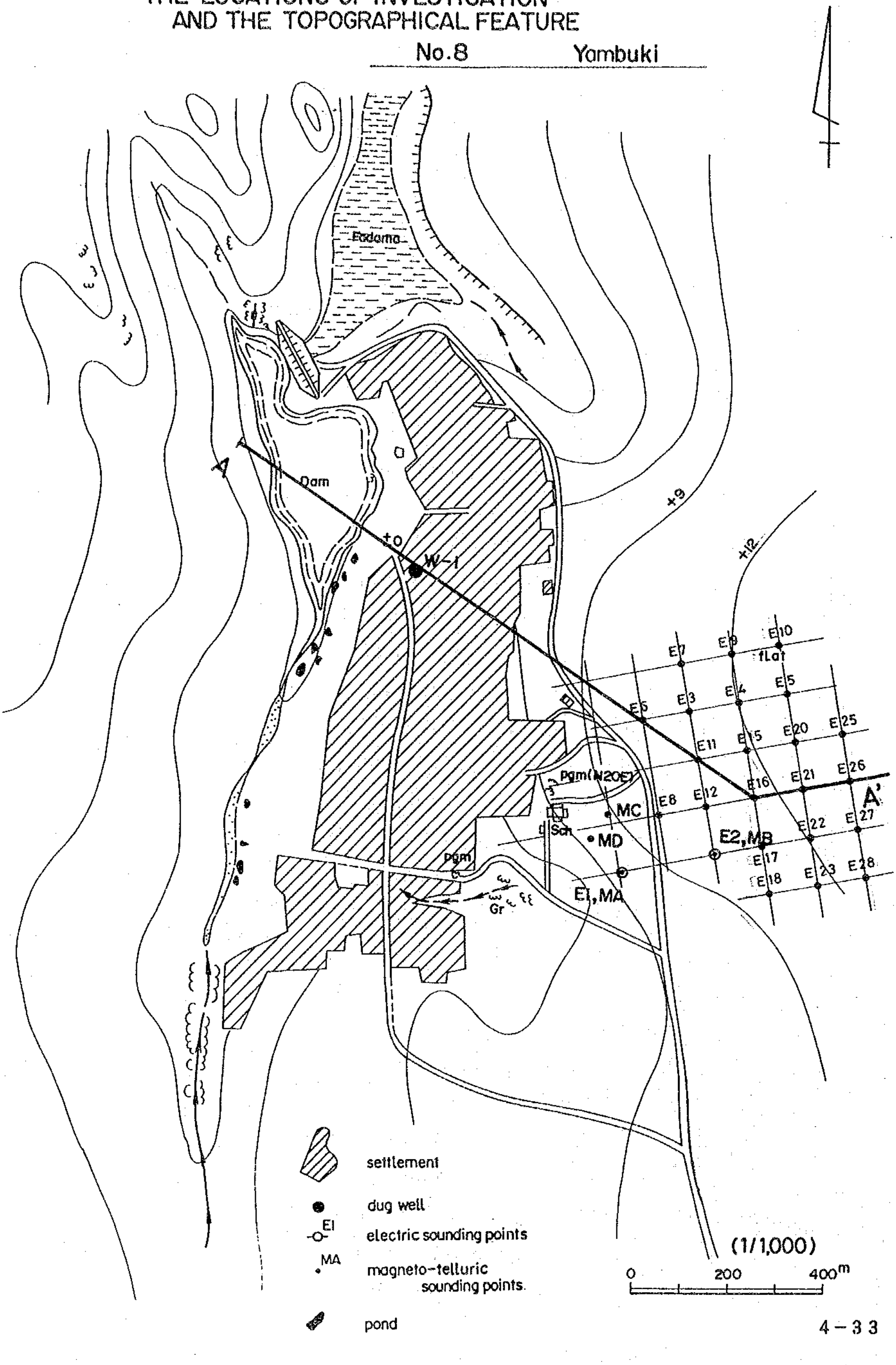
| Borehole No. | Depth(m) | S.W.L.(m) | S.C.(m³/d/m) |
|---|---|---|---|
| NW 3 | 40.0 | 29.19 | 3.39 |
| NW 4 | 43.0 | 28.76 | 4.97 |
| NW 5 | 25.0 | 3.05 | 6.70 |
| NW 6 | 31.0 | 5.04 | 1.92 |
| NW 7 | 25.0 | 12.60 | 216.00 |
| NW 8 | 37.0 | 13.63 | 1.19 |
| NW 9 | 37.0 | 14.04 | 59.59 |
| NW 14 | 25.0 | 10.51 | 17.44 |
| NW 15 | 24.0 | 11.85 | 5.19 |
| SW 1 | 40.0 | 31.41 | 106.25 |
| SW 2 | 49.0 | 29.60 | 4.14 |
| SW 3 | 41.0 | 24.99 | 3.97 |
| SW 4 | 34.0 | 24.33 | 55.74 |
| SW 7 | 73.0 | 38.75 | 54.74 |
| SW 8 | 73.0 | 38.26 | 4.50 |

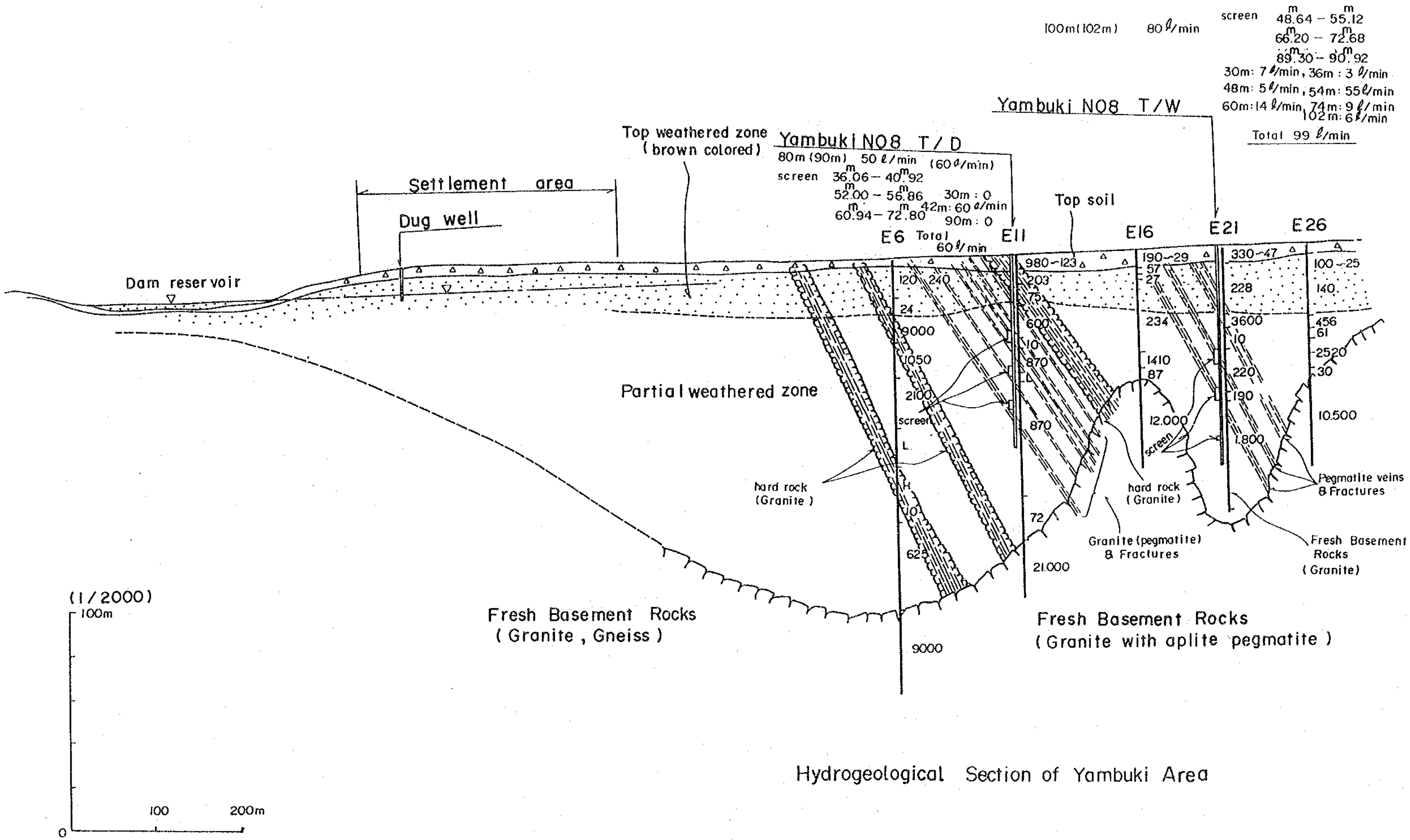
S.W.L. : Static Water Level
SC : Specific Capacity

1/100,000 0 50 km

THE LOCATIONS OF INVESTIGATION
AND THE TOPOGRAPHICAL FEATURE

No.8 Yambuki






Hydrogeological Section of Yambuki Area

Isopach Map of the Fresh Basement Rocks in Yambuki

(Map Showing the depth to the fresh basement rocks)