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Geophysical Investigation of the Omaruru Alluvial Plains, Namibia.

(U.Noell*, D.Howard*, A. Bittner*, E.Tordiffe*.)

ABSTRACT

The Omaruru Alluvial Plains (OMAP) on the coast of Namibia are spread over 2600 Km^2 of the Namib desert. It is inferred that these plains are underlain by Palaeo channels of the southward migrating course of the Omaruru River and that the possibility exists that these alluvium filled channels may contain substantial amounts of stagnant groundwater. The aim of the investigation is to establish the potential of the aquifer as an interim (additional) source of water for three local towns.

The alluvium consists of up to 200 metres of moderately sorted coarse sands, suspended in a clay matrix and cemented to greater and lesser degrees by calcrete. These beds have been deposited on felspathic granite, schist, gneiss and volcanics of 500 to 700 Mil. years.

The first part of the investigation consisted of helicopter borne geophysical measurements, including electromagnetic, magnetic and spectrometric measurements. This investigation was performed by the Federal Institute for Geosciences and Natural resources of Germany, under the technical co-operation agreement between the Republic of Namibia and the Federal Republic of Germany.

This was followed by a surface geophysical study by the Department of Water Affairs, Namibia; using vertical electric soundings, time domain and frequency domain electromagnetic methods.The ground geophysics supported the findings of the heliborne survey and a programme of exploration drilling has been started.

Initial evaluation of the drilling results indicates that although there is thick alluvium (200 metres), the lack of any significant recharge has resulted in the almost complete discharge of water, 50 kilometres down stream, into the Omaruru delta.

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Outline of the verbal presentation to be given at the Conference "Africa Groundwater 96"

Title: Geophysical Investigation of the Omaruru Alluvial Plains, Namibia

<u>Structure:</u>

1. Introduction
2. Hydrogeological Concepts
3. Airborne Geophysical Investigation, Modelling and Interpretation
4. Ground Based Geophysical Investigation, Modelling and Interpretation
5. Drilling Results
6. Conclusions and Recommendations

Assumed time for the presentation: 10 min

All sections marked with the ■ are contingencies which will be presented if more then 10min are allocated to the presentation.

1. Introduction

The central coast of Namibia (OHP Transparency 1) with i. a. the growing towns of Swakopmund and Walvisbay faces special problems concerning the water supply.

⇒ presently supplied with groundwater from Kuiseb and OMDEL aquifers
⇒ very arid climate, Namib desert, basically no precipitation except mist
⇒ limited recharge to the aquifers even when runoff appears (OMDEL Dam project !)

To alleviate this difficult situation an investigation program was launched to investigate palaeochannels of the Kuiseb river and the Omaruru river with geophysical methods. Parts of the investigations were performed by the Federal Institute of Geosciences and Natural Resources of Germany, under the technical co-operation agreement between the Republic of Namibia and the Federal Republic of Germany.

⇒ Airborne geophysical measurements (EM, Magnetics, Spectrometrics) ⇒ BGR
⇒ ground based geophysical measurements ⇒ BGR (Kuiseb), DWA (OMAP)
⇒ investigation drilling (DWA) and test pumping (Kuiseb)

In both project areas extended palaeo channels were found and mapped with the geophysical methods

In both project areas extended palaeo channels were found and mapped geophysical methods.

⇒ airborne EM very successful tool in the investigation of an alluvial environment
(penetration depth ≈ 80m but (f (ρ))

⇒ ground based geophysical investigation necessary for deeper penetration.

(TDEM penetration depth > 200m but (f (ρ,s))

⇒ interpretation in terms of water equivocal

⇒ evaluation of existing borehole data necessary to get a guideline for the interpretation (layering, water content, formation factor, ...)

2. Hydrogeological concepts of the Omaruru Alluvial Plains

The Omaruru River is a large ephemeral river of western Namibia (OHP Transparency 2).

⇒ catchment area 14 687 km^2

⇒ rainfall variation within the catchment from 450mm/a to 0-50mm/a

⇒ all 11.3 years a major flood event with an average runnoff of 13.2Mm^3/year (46 years data, not all of equal quality)

Three main processes have been active in the formation of the palaeochannels

⇒ tectonic processes

⇒ sea level fluctuations

⇒ fluvial processes

Three successive stages in the development of the present alluvial stratigraphy can be identified

⇒ initial phase of erosion of a series of channels which resulted in the present bedrock topography

⇒ period of deposition of the alluvial deposits within the channels

⇒ Uplift in the order of 100m since Tertiary times, river was shifted to the south from its initial alluvial bed into a newly created depression

The Omaruru Alluvial Plains (OMAP) are the upper part of the initial alluvium bed of the present Omaruru River.(OHP Transparency 3)

⇒ it was assumed that palaeo channels within this plains may contain stagnant groundwater of brackish or saline groundwater.

The aim of the investigation was to find out

⇒ if and where palaeo channels (single, multiple channels)

⇒ dimension of channels

⇒ If water in the channels

⇒ amount of water and quality

Presently water is [redacted] the OMDEL aquifer (OHP Transparency 4)

⇒ not a real Delta [redacted]
⇒ consists of a ma[redacted]rthern channel and two elevated channels
⇒ about 8.5Mm^3/a [redacted]ped

⇒ 4.5 Mm^3/a safe [redacted] Mm^3/a flood, 3.5 Mm^3/a throughflow)
⇒ 3.5 Mm^3/a from [redacted] recharge (still no major flood event)

3. Airborne Geophysical Investigation, Modelling and Interpretation

1993 an area of 2 600km², the whole Omaruru Alluvial Plains, were surveyed by means of airborne geophysics, applying electromagnetic, magnetic and spectrometric methods.

⇒ flight line spacing 1km
⇒ EM with three frequencies (386 Hz, 3 631 Hz, 30 740 Hz)
⇒ EM bird 30m above the ground (45m below helicopter), coil spacing 7.98m and 6.32m for 30 740 Hz
⇒ four samples per second, intervals of about 10m with EM and Magnetic measurements
⇒ Magnetic measurements : 0.01nT sensitivity, bird 30m below the helicopter
⇒ Doppler and GPS navigation systems (recorded twice a second)

Interpretation of the EM measurements

⇒ ip and op signals are recorded, app. resistivity and app. depth calculated
⇒ calculation of centroid depth (maximum investigation depth = 1.5 * centroid depth)

⇒ centroid depth = d_a + [redacted] (C) (Schmucker, Weidelt, Sengpiel)

⇒ simultaneous inversion of all ip and op data using a five layer model

⇒ general matrix inv[redacted]single value decomposition) combined with the Markquardt method

⇒ high resistive cover (first layer) introduced for the initial model
⇒ results are given as maps of the spatial resistivity distribution in the different layers
⇒ results are also given as vertical sections

OHP Transparency 5 shows the vertical section along flight line 16.

⇒ two palaeo channels with low resistivity indicating the alluvium
⇒ bedrock high between the channels and between the present Omaruru and the main channel
⇒ low resistivity values (3 - 12 Ωm) were interpreted as indicating brackish water ?
⇒ channel depth exceeds penetration depth of the EM system

OHP Transparency 6 shows the spatial resistivity distribution within the fifth layer..

⇒ two palaeo channels, main channel has an lateral extension of about 100km and the width varies between 2- 15km.
⇒ resistivities vary between 3-20Ωm within the channels
⇒ excellent picture about the spatial location of the channels
⇒ excellent guide for the planning of the follow up ground based survey

4. Ground Based Geophysical Investigation, Modelling and Interpretation

Different ground based geophysical investigation methods were applied
(Location of the sites see OHP Transparency 7)
⇒ dc- resistivity soundings (13 sites) (Schlumberger configuration)
⇒ Time Domain electromagnetic measurements (soundings) with the SIROTEM (7 sites)
⇒ Frequency Domain Electromagnetic measurements with the EM34 (6 sites)

The investigation was especially aimed at the resistivity of the alluvium, the depth and the location of the channels.

"Calibration" measurements in OMDEL

dc- soundings at three sites, airborne EM over the whole OMDEL

⇒ layering known from boreholes, five layer model for OMAP derived from this
⇒ dc soundings could be modelled perfectly with the five layer assumption
⇒ this model was therefore used as guideline for modelling of the OMAP measurements
⇒ water quality known, estimation of the TDS value from the resistivity value seems to give reliable results.

One example for DC-soundings in OMAP (OHP Transparency 8)

⇒ AB/2 = 200m, weak signal at greater spacing because of the dry surface layer
⇒ modelling as a 5 layers case (as the helicopter EM data)
⇒ bedrock depth estimated as 136m (drilling result 141m)
⇒ AB spacing to small to get a reliable result!!!!!!!!!!!!!
→ comments: takes quite a time

One example for TDEM measurements in OMAP (OHP Transparency 9)

⇒ coil of 100m x 100m
⇒ quick measurement
⇒ modelling as a five layers case
⇒ bedrock depth estimated as 195m (drilling result 198m)
⇒ induction method advantageous at greater depth.

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⇒ comments: good data quality by stacking 512 or 1024 measurements
interpretation ne[redacted] good computer program
no good idea ab[redacted]e results before the interpretation is made

One example for EM34 measurements in OMAP (OHP Transparency 10)

⇒ limited depth penetration
⇒ not recommended as sounding tool in the layered case (dc-soundings or TDEM recommended)
⇒ easy measurement for the resistivity of the upper parts of the alluvium (average value)
⇒ should always be combined with a sounding to get an idea of the layering
⇒ useful as a quick mapping tool (near surface bedrock will most probably show up as resistivity high compared to the deep alluvium filled channels)

Summary:

TDEM method advantageous in case of

⇒ dry surface
⇒ highly conductive layers (clay layers !!)
⇒ deep alluvium
⇒ varying bedrock topography in a small scale

All electrical and electromagnetic methods give as result the resistivity and the thickness of the different layers.

⇒ equivalence problem, especially with dc soundings

For interpretation in terms of water additional information urgently required

⇒ principle layering
⇒ water or not
⇒ TDS value of the water ⇒⇒ formation factor ⇒⇒ water quality estimation at other places

5. Drilling results

⇒ Two boreholes in the probably deepest part of the main channel (OHP Transparency 7)
⇒ one borehole nearer to OMDEL

Transparency 7)

⇒ one borehole nearer to OMDEL

⇒ aimed at : water?, layering? , water quality ?

⇒ drilling Dec. 95

→ mud rotary and/or air percussion

Deep channel was confirmed:

⇒ 198m, 141m and 110m at flight line 16
⇒ results of airborne and ground based geophysics was confirmed in terms of the existence and the depth (ground based methods) of the channel
⇒ boreholes were dry, only one water sample could be taken (from mud drilling?)

Layering of the alluvium

⇒ gravel, sand, sometimes calcareous, beds of clay (54m thick at TP5)
⇒ typical alluvium, sometimes badly sorted
⇒ fluviatile deposition
⇒ bedrock consisted of granite, basalt and amphibolite of Damara age

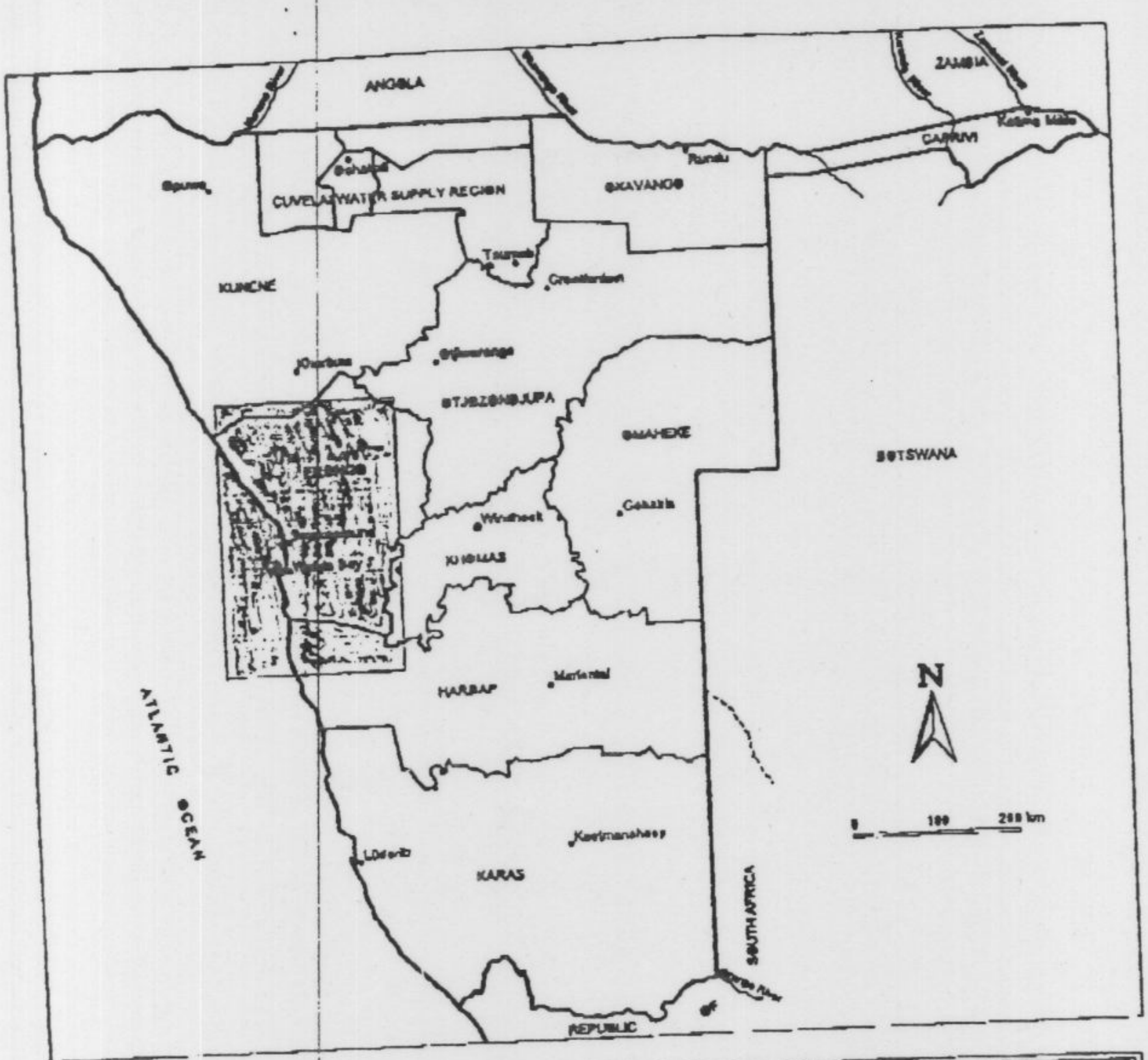
No resistivity log possible because boreholes were dry:

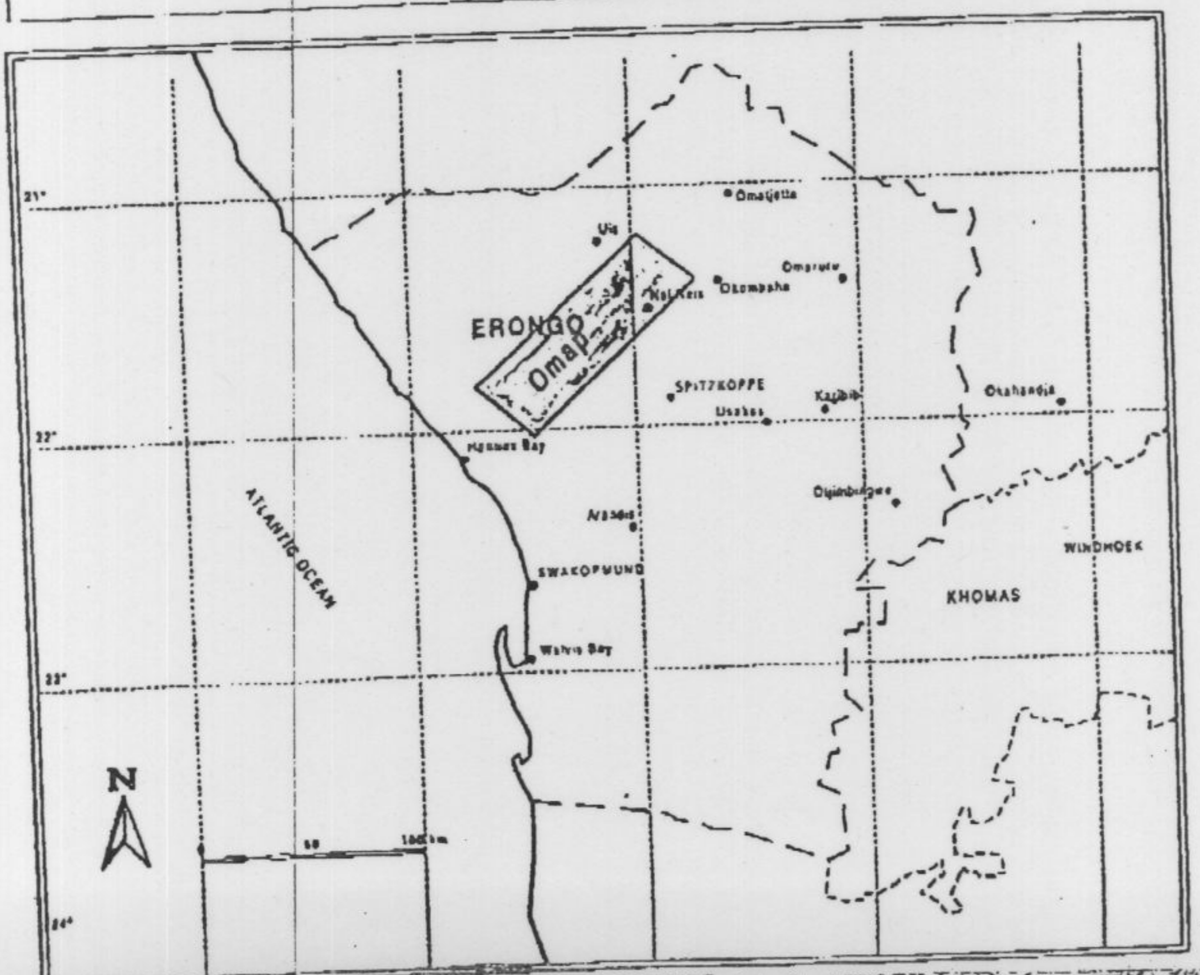
⇒ problem!!!! Why shows the dry alluvium such a low resistivity?????
⇒ higher clay content than OMDEL (not confirmed by the drilling and unlikely if our assumption of the deposition is correct)
⇒ salty crustations within the sediments, ... ???

6. Conclusions and recommendations

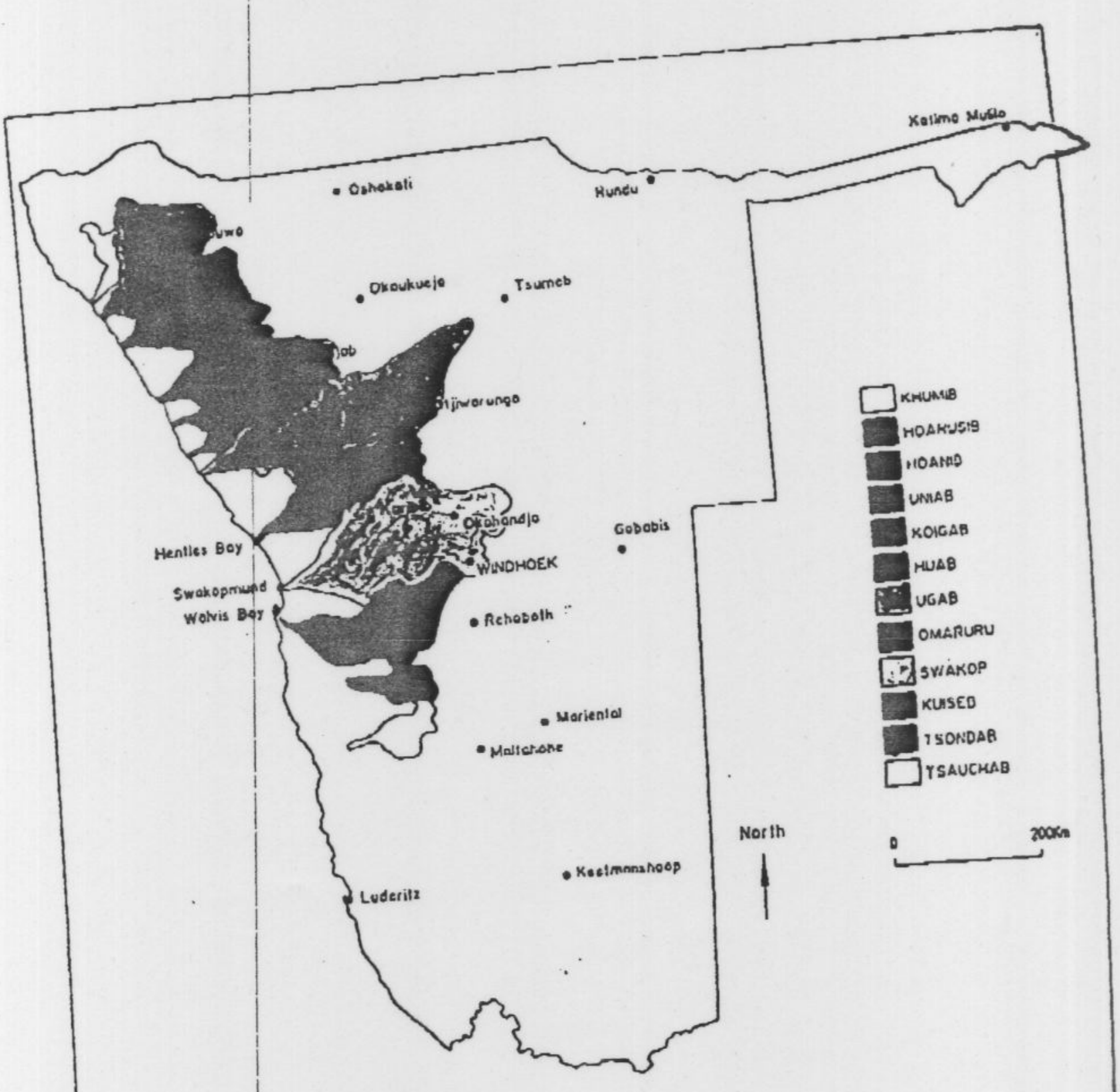
⇒ airborne EM ideal for the investigation of palaeo channels and alluvial deposits
⇒ ground based follow up required especially if channel depth exceeds the penetration depth of the airborne system
⇒ five layer assumption was successful model to get the real bedrock depth with the ground based methods (dc-soundings and TDEM)
⇒ Interpretation in terms of water not correct although calibrated at the similar OMDEL.
⇒ borehole information from the investigated area are of major importance to interpret the measured resistivities correctly.
⇒ still open questions concerning OMAP (northern channel ?, multiple channel system in main channels ?, all channels dry ??, everywhere ?)

OHP 1


ANGOLA
ZAMBIA
CAPRIVI
Rundu
KAVANGO
CUVELAI WATER SUPPLY REGION
KUNENE
Tsumeb
Grootfontein
OTJOZONDJUPA
OMAHEKE
BOTSWANA
Windhoek
Gobabis
KHOMAS
Walvis Bay
HARDAP
Mariental
ATLANTIC OCEAN
N
0 100 200 km
Keetmanshoop
Lüderitz
KARAS
SOUTH AFRICA
REPUBLIC

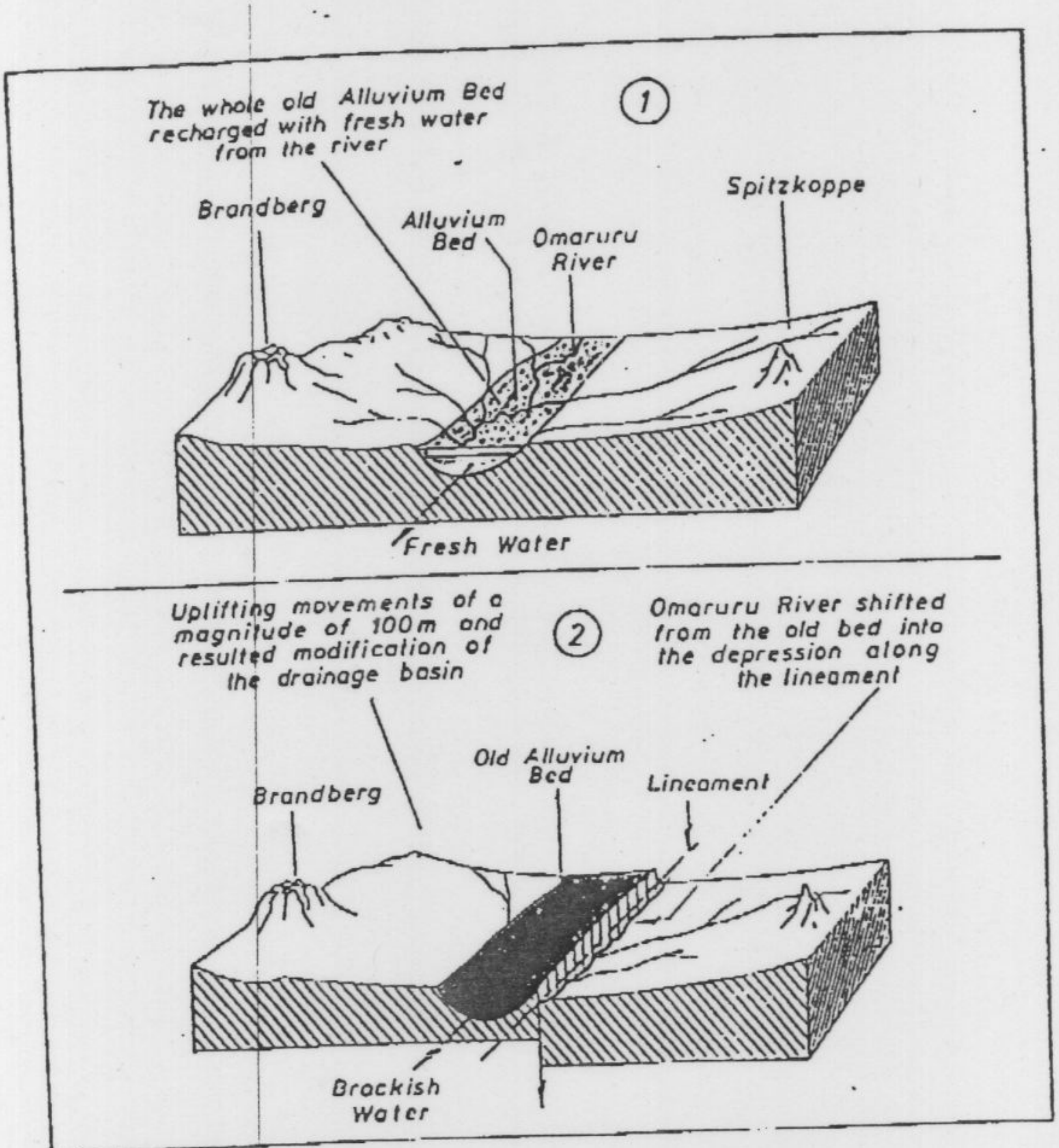

21°
Omatjette
Uis
Omaruru
Okombahe
ERONGO
Omap
SPITZKOPPE
Usakos
Karibib
Okahandja
22°
Henties Bay
Otjimbingwe
ATLANTIC OCEAN
SWAKOPMUND
WINDHOEK
KHOMAS
Walvis Bay
23°
N
50
100 km
24°

OHP 2 original colour coded

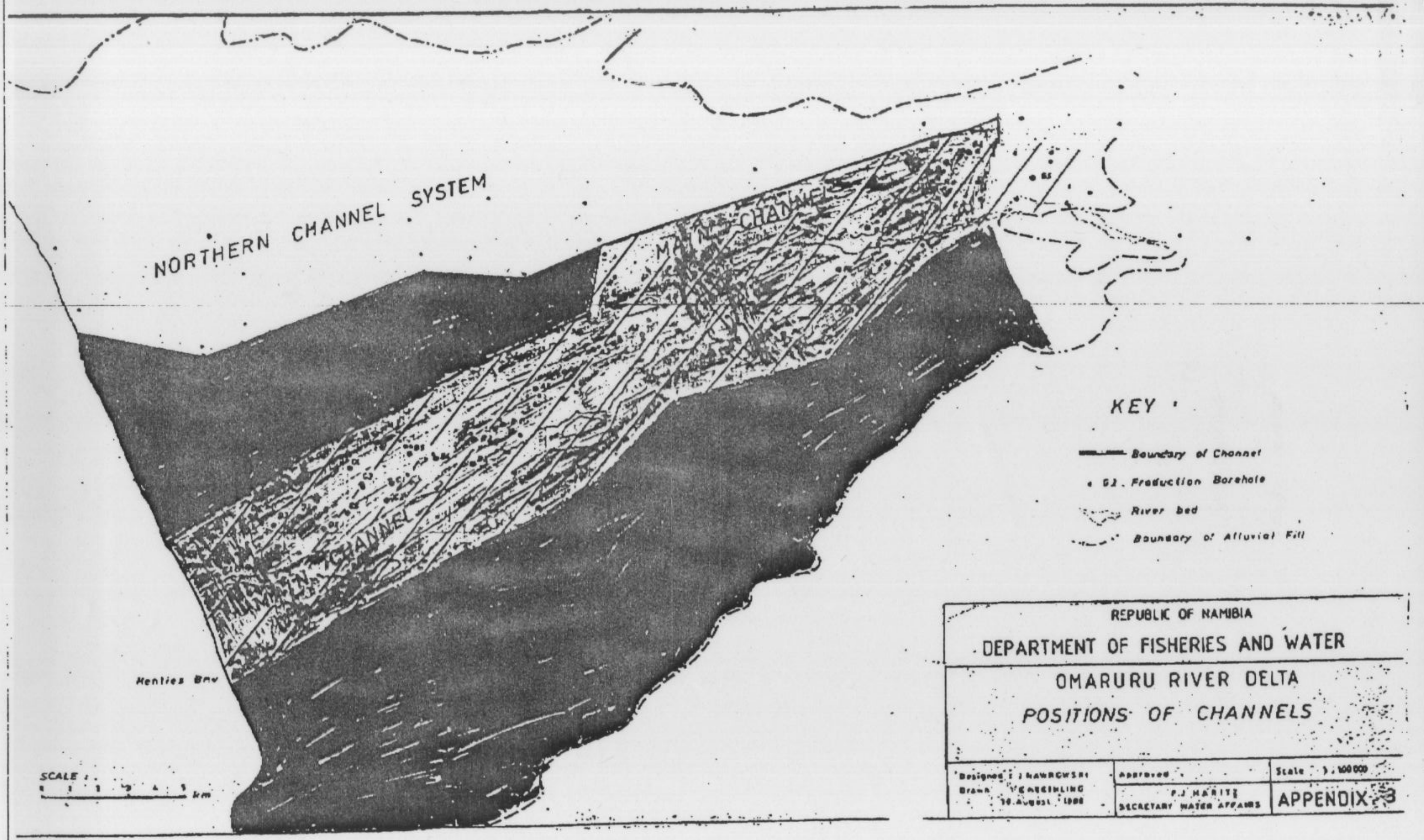


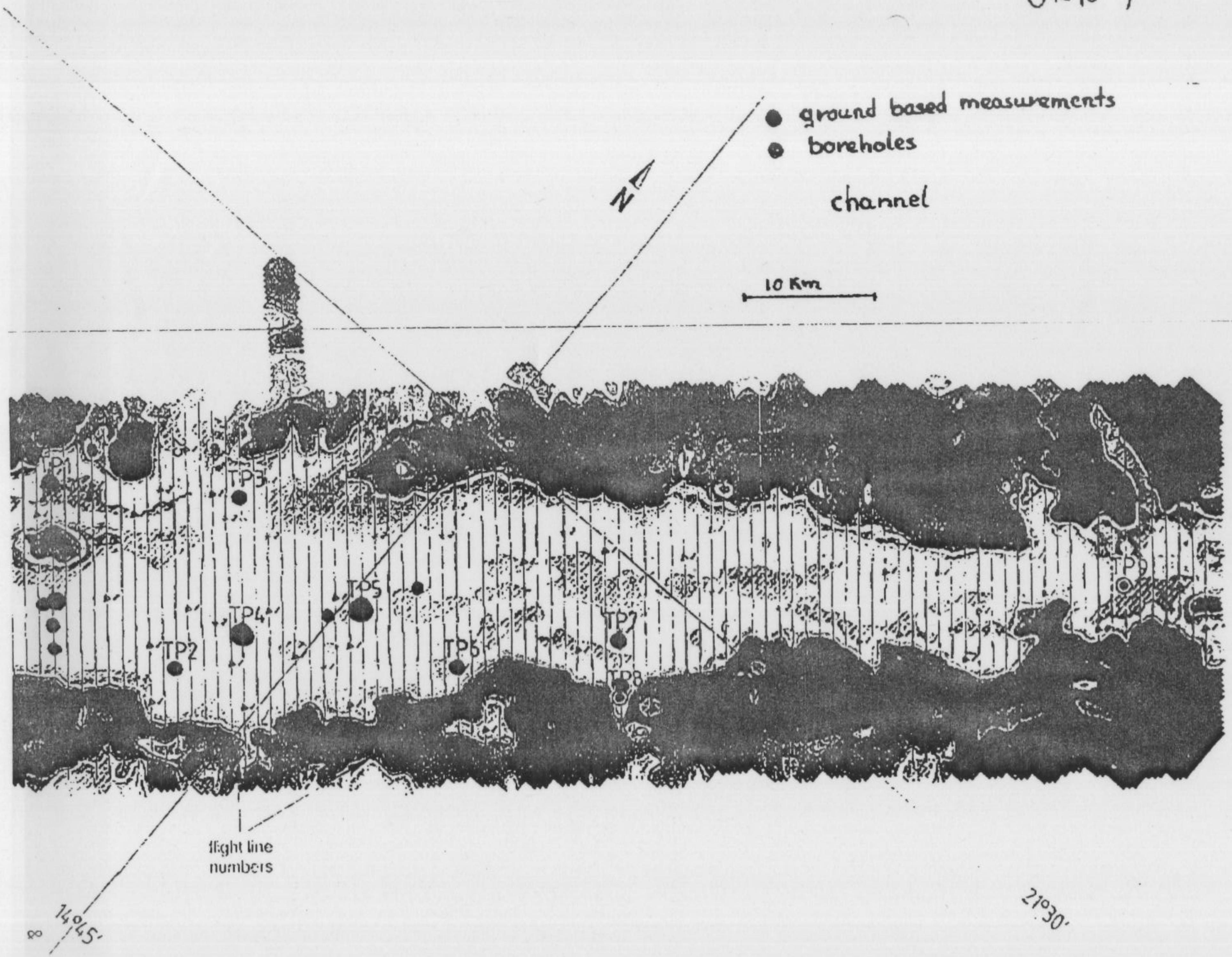
Twelve major ephemeral rivers flow across western Namibia. Their catchments, the area from which rainfall drains into the river, cover nearly a quarter of the country

OHP 3


1
The whole old Alluvium Bed recharged with fresh water from the river
Brandberg
Alluvium Bed
Omaruru River
Spitzkoppe
Fresh Water
2
Uplifting movements of a magnitude of 100m and resulted modification of the drainage basin
Omaruru River shifted from the old bed into the depression along the lineament
Brandberg
Old Alluvium Bed
Lineament
Brackish Water

OHP4


NORTHERN CHANNEL SYSTEM
MAIN CHANNEL
MAIN CHANNEL
Henties Bay
SCALE
km
KEY
Boundary of Channel
Production Borehole
River bed
Boundary of Alluvial Fill
REPUBLIC OF NAMIBIA
DEPARTMENT OF FISHERIES AND WATER
OMARURU RIVER DELTA
POSITIONS OF CHANNELS
Designed
Drawn
Approved
SECRETARY WATER AFFAIRS
Scale
APPENDIX 3

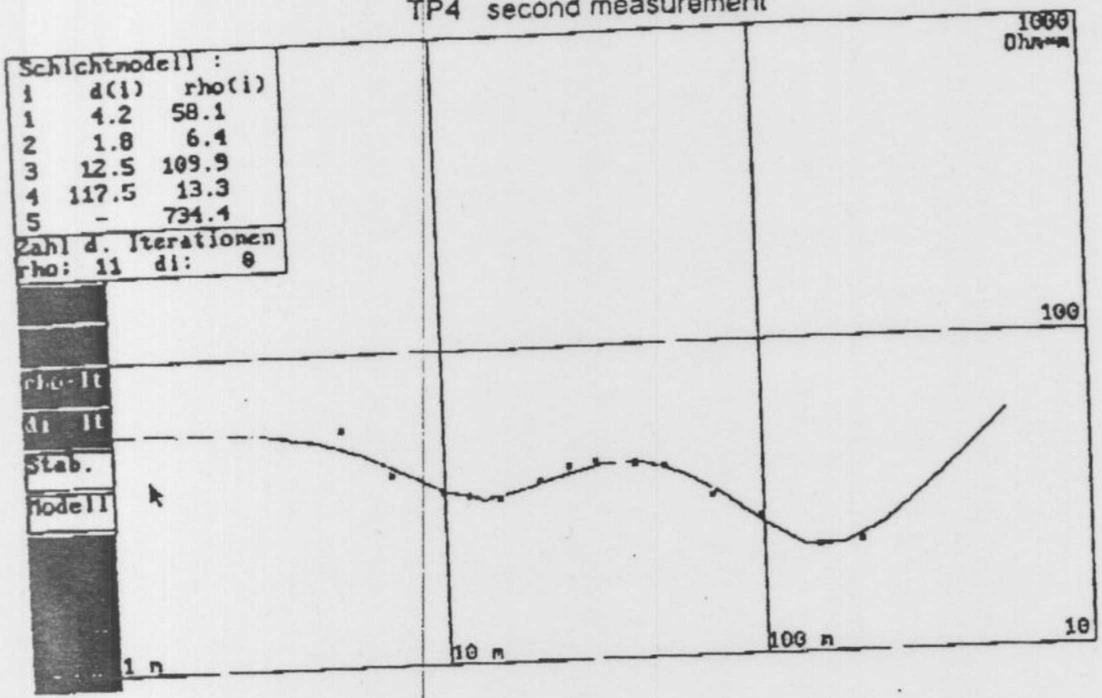


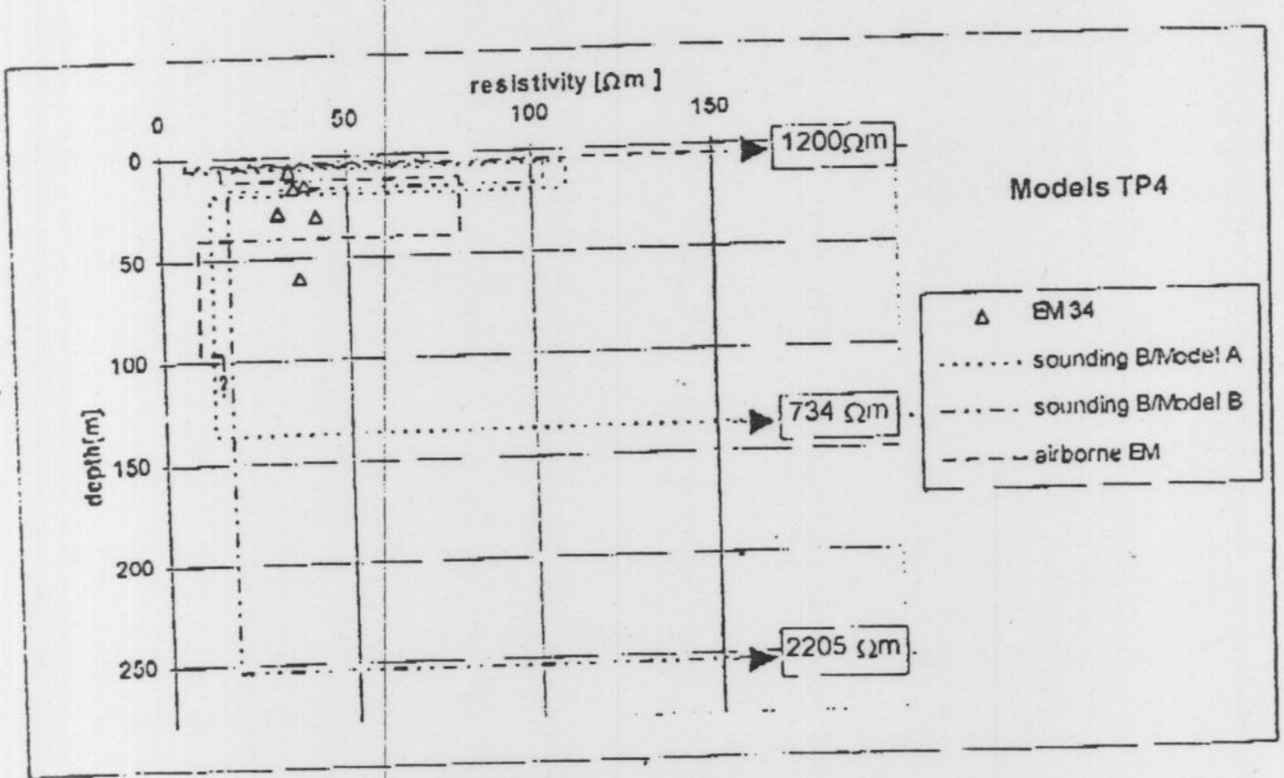
ground based measurements
boreholes
channel
N
10 Km
TP1
TP2
TP3
TP4
TP5
TP6
TP7
TP8
TP9
flight line numbers
14°45'
21°30'

8

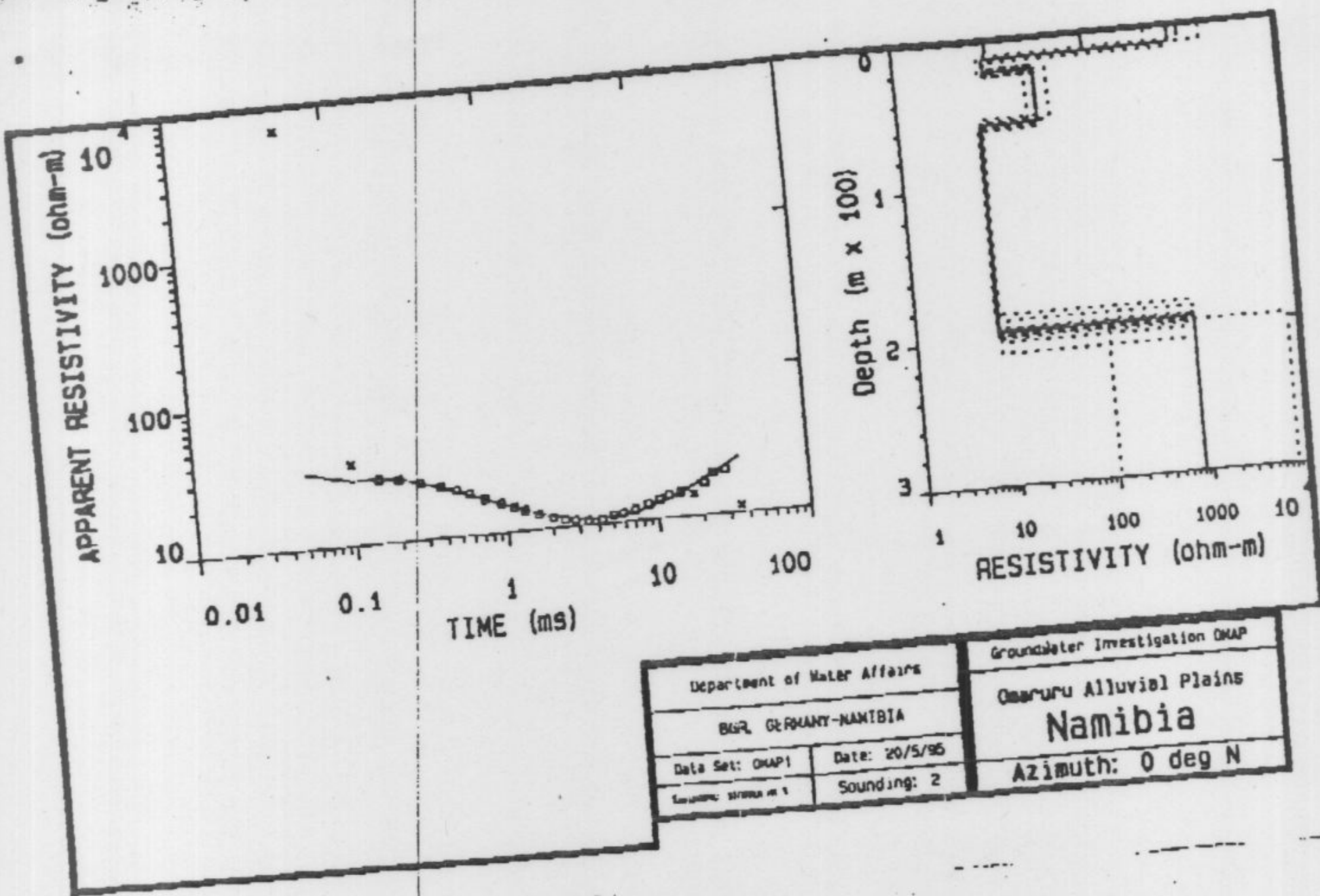
OHP 8

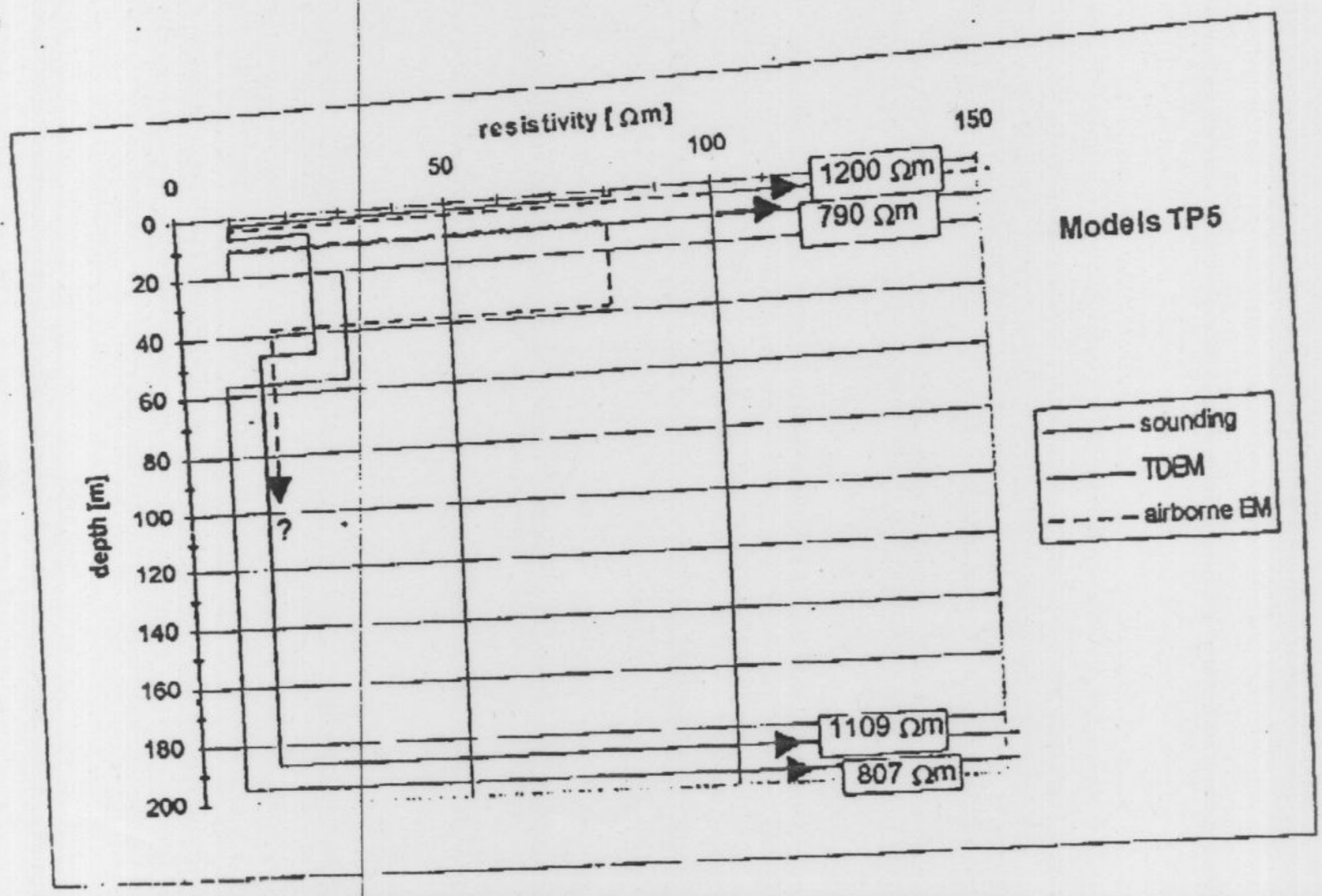
TP4 second measurement

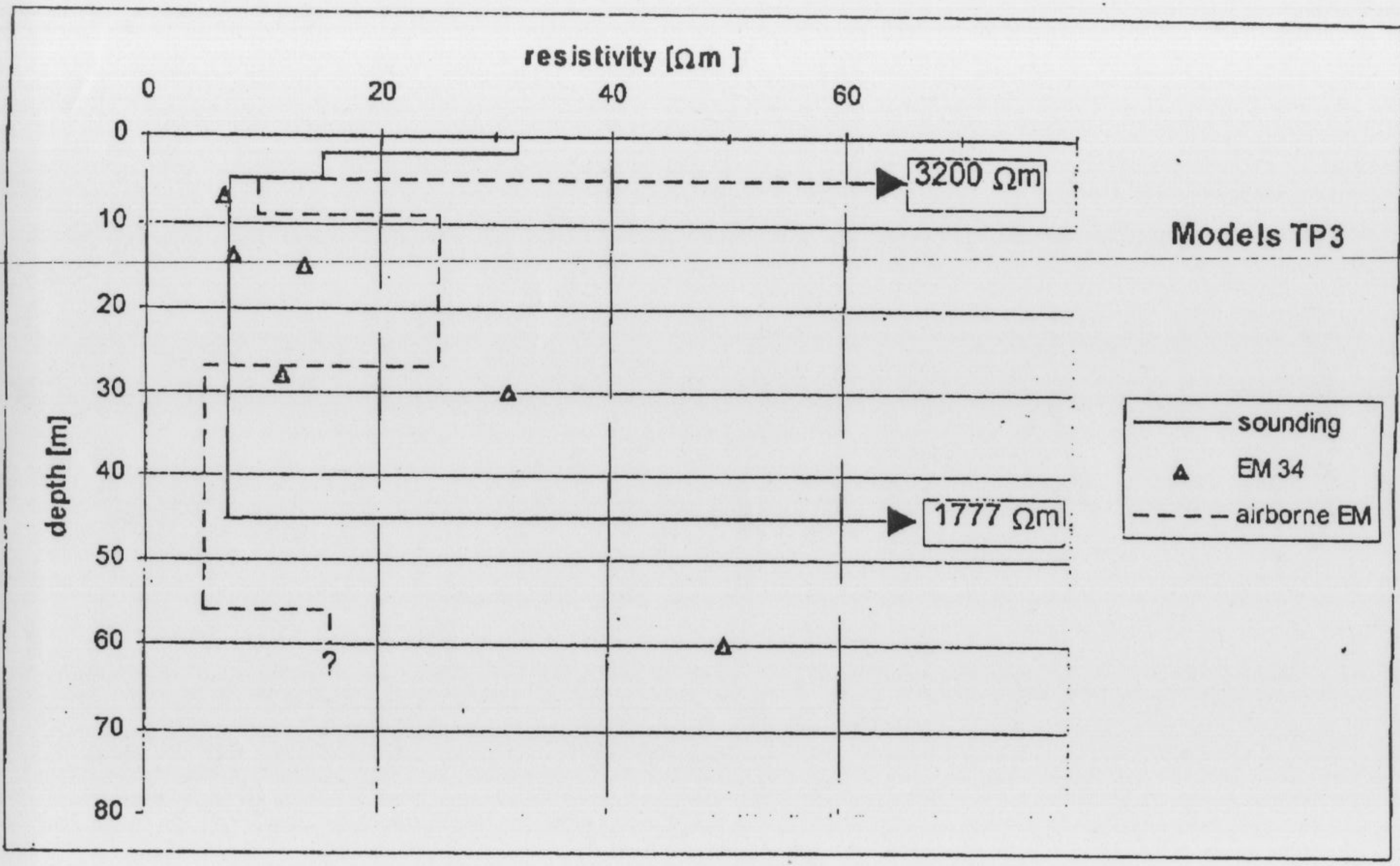




01+P4


APPARENT RESISTIVITY (ohm-m)
TIME (ms)
Depth (m x 100)
RESISTIVITY (ohm-m)
Department of Water Affairs
BGR, GERMANY-NAMIBIA
Data Set: OMAP1
Date: 20/5/95
Sounding: 2
Groundwater Investigation OMAP
Omaruru Alluvial Plains
Namibia
Azimuth: 0 deg N


resistivity [Ωm]
depth [m]
1200 Ωm
790 Ωm
1109 Ωm
807 Ωm
Models TP5
sounding
TDEM
airborne EM


Models TP3
resistivity [Ωm]
depth [m]
0
20
40
60
0
10
20
30
40
50
60
70
80
3200 Ωm
1777 Ωm
?
sounding
EM 34
airborne EM