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1390

MIDDLE BORE EXPERIMENTAL

CSAMT SURVEY.

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COMALCO ALUMINIUM LTD.

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LIST OF FIGURES

Figures:

INTRODUCTION:

An experimental CSAMT (Controlled Source Audio Magno-Telluric) survey was undertaken over two lines on the Middle Bore magnetics and gravity grid between 28th April and 2nd May, 1985 by Zonge Engineering and Research Organisation. Figure-1 shows the location of the survey. The field crew consisted of W. Clapper and P. Hoffman of Zonge Engineering and Research Organisation and L. Diekman as assistant of Comalco Aluminium Limited.

The CSAMT method detects small changes in resistivity within the earth hence enabling subsurface geological mapping when geology is related to changes in resistivity, such as faults and shear zones, lithology changes, the presence of metallic sulfides and changes in the nature of formation fluids such as salinity and permeability changes.

PROCEDURE:

Two separate lines of CSAMT data were acquired; 34 stations along seismic line 84-0092 and 15 stations along line B4 of the Middle Bore gravity and magnetic grid as shown in figure 5. The field set-up is shown in figure 3. Close spaced detailed station readings were recorded with 60 metre receiver dipole dimensions and semi-detailed station readings were recorded with 180 metre receiver dipole dimensions. Subsurface resolution in both cases is approximately equivalent to the receiver dipole dimensions. The vast majority of measurements were within the far field region.

A series of air-wave tests were undertaken to adjust for atmospheric transmission of EM waves from the transmitter dipole and an overlap test of 180m and 60m receiver dipoles served as a check of data validity.

The current was induced into the ground via a grounded dipole controlled by a GTT-25 transmitter. Transmitted currents ranged between 10 and 12 amps. Both electric E-field and the magnetic H-field were measured. The E-field induced by the transmitter dipole was measured by a grounded receiver dipole. The horizontal H-field was measured perpendicular to the E-field by a receiver coil array. The apparent resistivity of the ground below and between the receiver dipole was calculated by

$$\text{Apparent (Cagniard) resisitivity} = (E/H)^2 \times 1/(5f) \qquad \text{-(A)}$$

where E = magnitude of the electric E-field
H = magnitude of the magnetic H-field
f = frequency of the induced current.

The frequency spectrum was measured in binary increments from 2 to 2048 hertz. Lower frequencies have greater depth of penetration hence the measured spectrum produced a vertical profile at each station. The succession of stations along the survey lines thus generated 2-D apparent resistivity (and phase) profiles. The effective depth of penetration for a given frequency, f, through rocks of apparent resistivity, p, is:

$$\text{Effective depth of penetration} = 503\,(p/2f)^{\frac{1}{2}} \qquad \text{-(B)}$$

$$= 356\,(p/f)^{\frac{1}{2}} \qquad \text{-(C)}$$

The effective depth of penetration is $1/(2)^{\frac{1}{2}}$ x the skin depth, s, which is

$$S = 503\,(p/f)$$

The skin depth of an EM wave is the depth at which the amplitude of the wave is attenuated to 1/e of its initial value. Hence depth of penetration increases with decreasing frequency.

Measurements of the induced AMT field at a distance greater than $3(2)^{\frac{1}{2}}$ x effective depth of penetration lie within the "far-field" and apparent resistivities calculated by the above equation are within 10% of the "true" apparent resistivities because the transmitted AMT wave can be approximated by a plane wave. Measurements which lie within the "near-field" (ie. measurements of the induced AMT field at a distance less than $3(2)^{\frac{1}{2}}$ x effective depth of penetration) result in apparent resistivities which are higher than the "true" apparent resistivities in cases where a conductive layer overlies a non-conductive layer. CSAMT data in the near field exhibit severe apparent resistivity contrasts and resistivity contrasts are often magnified.

The effect of the near-field may be removed by mean value deconvolution of apparent (cagniard) resistivity data using a mean value curve obtained from the regional background resistivity response. The process of normalising masks horizontal resistivity layering effects but emphasises lateral changes in resistivity between stations. The normalisation process is only approximate and calculations of the fields in the near field region must include the geometry and location of the transmitter dipole if the "true" apparent resistivities are to be calculated.

The majority of the CSAMT Data for the Middle Bore survey lie within the far field, being more than three skin depths (3S) away from the transmitter dipole and within a right circular cone of 45° apex angle with its axis normal to the transmitter dipole, passing through the transmitter dipole centre, where the apex is located.

THEORETICAL CONSIDERATIONS OF THE CSAMT METHOD:

In the "far-field" region the E-and H-fields are plane waves and the impedence Z(w) at the surface of a horizontal layered earth, with respect to resistivity, is given by the ratio:

$$Z(w) = E_x(w)/H_y(w) \qquad -1$$

where E_x is the E-field measured in the x direction as a function of angular frequency, w, and H_y is the H-field measured in the y direction (where x and y are orthogonal) as a function of angular frequency, w.

For a homogenous half-space:

$$Z(w) = (iw\mu p)^{\frac{1}{2}} \qquad -2$$

Where μ is the magnetic permeability of the half-space (=4x pi x 10e-7), $i= (-1)^{\frac{1}{2}}$ and p is a resistivity function,

or

$$p = (Z(w))\ ^2 iw\mu \qquad -3$$

$$=(E_x(w)/H_y(w))^2/iw\mu \qquad -4$$

$$= (E_y(w)/H_{x(w)})^2/iw\mu \qquad -5$$

Note that in an earth in which bulk formation resistivities are neither only homogenous nor horizontally distributed the equality of equations 4 and 5 does not follow i.e.

$$(E_x(w)/H_y(w))^2/iw\mu \neq (E_y(w)/H_x(w))^2/iw\mu \quad -6$$

The equation for p possesses real and imaginary parts. The amplitude of p, /p/ is the resistivity scaler component i.e:

$$p = E_x/H_y\ ^2\ (w\mu) \quad -7$$

or apparent resistivity = $(E_x/H_y)^2 \times 1/5f$ -8

where f is the frequency in hertz, as before and w= 2 x pixf
and a phase component:

$$\text{phase} = \tan^{-1}(\text{Im } Z(w) / \text{Re } Z(w)) \quad -9$$

However, in the real earth, inequality 6 holds and the impedence Z (w) then becomes the tensor $Z_{ab}(w)$ i.e.

$$E_a(w) = Z_{ab}(w)\, H_b(w) \quad -10$$
$$E_a = Z_{aa}H_a + Z_{ab}H_b \quad -11$$
$$E_b = Z_{bb}H_b + Z_{ba}H_a \quad -12$$

in general, which relates the E- and H-fields at the surface by a tensor.

Similarly equation 7 becomes:

$$P_{ab}(w) = Z_{ab}(w)\ ^2/w\mu \quad -13$$

where $Z_{ab}(w)$ is derived from equations 11 and 12 in general and by equation 1 if a,b = 2.

The phase relation (equation 9) now becomes

$$phase_{ab}=\tan^{-1}(ImZ_{ab}(w)/ReZ_{ab}(w)) \qquad -14$$

The relations used to calculate the apparent resistivity (equation A) and phase (equation 9) are clearly inappropriate for complex resistivity distributions for which equations 13 and 14 should be used.

Because of the geologic complexity of the area surveyed the CSAMT sections produced are complex due to complex resistivity distributions and do not accurately represent geologic features. However, some general qualitative inferences can be made using the CSAMT data.

INTERPRETATION OF FIELD DATA:

Complexity of CSAMT measurements resulted from resistivity contrasts between the Permian and Mesozoic sediments and the underlying carbonates and from suspected structural features within the carbonates and deeper units. The Permian and Mesozoic sediments have much lower resistivities than the carbonates. The boundary between these two major resistivity units was intersected at approximately 160m depth in Middle Bore-1, which is between 32 hertz and 16 hertz on the CSAMT sections of figure 2 (using the skin-depth relation and the effective depth of penetration relation this boundary is picked at approximately 150m -170m).

The resistivity "low" centred below station 1344 (refer to figure 1, section 1), and penetrated by the Middle Bore-1 drill hole (30m southwest of station 1345) is probably due to a fluid filled shear zone. Middle Bore-1 intersected sheared carbonates below 160 metres and sheared basement below 394 metres. The minor amounts of sulfides that were intersected were too few by several orders of magnitude to account for, or to appreciably contribute to, the observed CSAMT resistivity "low".

The broad resistivity "high" at frequencies less than 32 hertz between stations 1334 and 1358 (refer to figure 2, section 1) is probably due to an up-faulted block between these stations. This zone corresponds to the modelled causative body of the magnetic anomaly and the faulted boundary at station 1334 can also be recognised from seismic data (Comalco seismic line 84-0092). Another possible fault is located between stations 1380 and 1386. The later corresponds to the termination of a strong reflector at 0.75 seconds TWT (approximately 1450 metres below surface) on the seismic data.

The low resistivities which were recorded to the south east of station 1310 on line 0092 (refer to figure 2, section 1) may be due to a combination of a thickening of the Mesozoic and Permian sections (and possibly a deeper and older section), as can be seen on the seismic data, and the presence of saline formation waters within these rocks. The depth penetrated by the CSAMT measurements at a transmitted frequency of 2 hertz in this low resistivity zone is approximately 560 metres which is well short of the top of the carbonates which is picked at 0.45 seconds TWT (i.e. 730 metres below surface) at station 1300 (ie. CSAMT station 1300, line 0092).

The resistivity low between stations 1362 and 1386 on line 0092 (refer to figure 2, section 1) is probably due to the presence of saline formation waters throughout most of the section down to the top of the carbonates and possibly within fractured carbonates at 16 hertz (166 metres below surface). The equivalent zone located on the seismic data (Comalco seismic line 84-0092) is dominated by disrupted and discontinuous reflectors below 0.7 sec TWT (below 1200 metres below surface) which is interpreted to represent a faulted zone.

There is no continuation of the low resistivity zone below station 1344 (line 0092) across to line B4 (refer to figure 4) 500 metres to the northeast. The interpreted faulted zone at station 1334 (line 0092) is probably continuous with an interpreted fault below station 3 on line B4, which is in agreement with interpretations of gravity and magnetic data.

A Summary interpretation is presented as figure 5.

<u>CONCLUSION</u>

The CSAMT data do not indicate the presence of a strongly conductive zone, such as would be expected from a massive metallic sulfide body, coincident with the magnetic and gravity anomalies. The moderately conductive zone which was penetrated by Middle Bore-1 is probably due to the presence of fluid within extensively sheared zones. This moderate conductivity zone does not have any detectable extension to the northeast.

CSAMT data, although strongly distorted due to the complexities of the geology and subsurface water distribution of the area, allows a qualitative interpretation which, in general, is in agreement with interpretations of seismic, magnetic and gravity data sets.

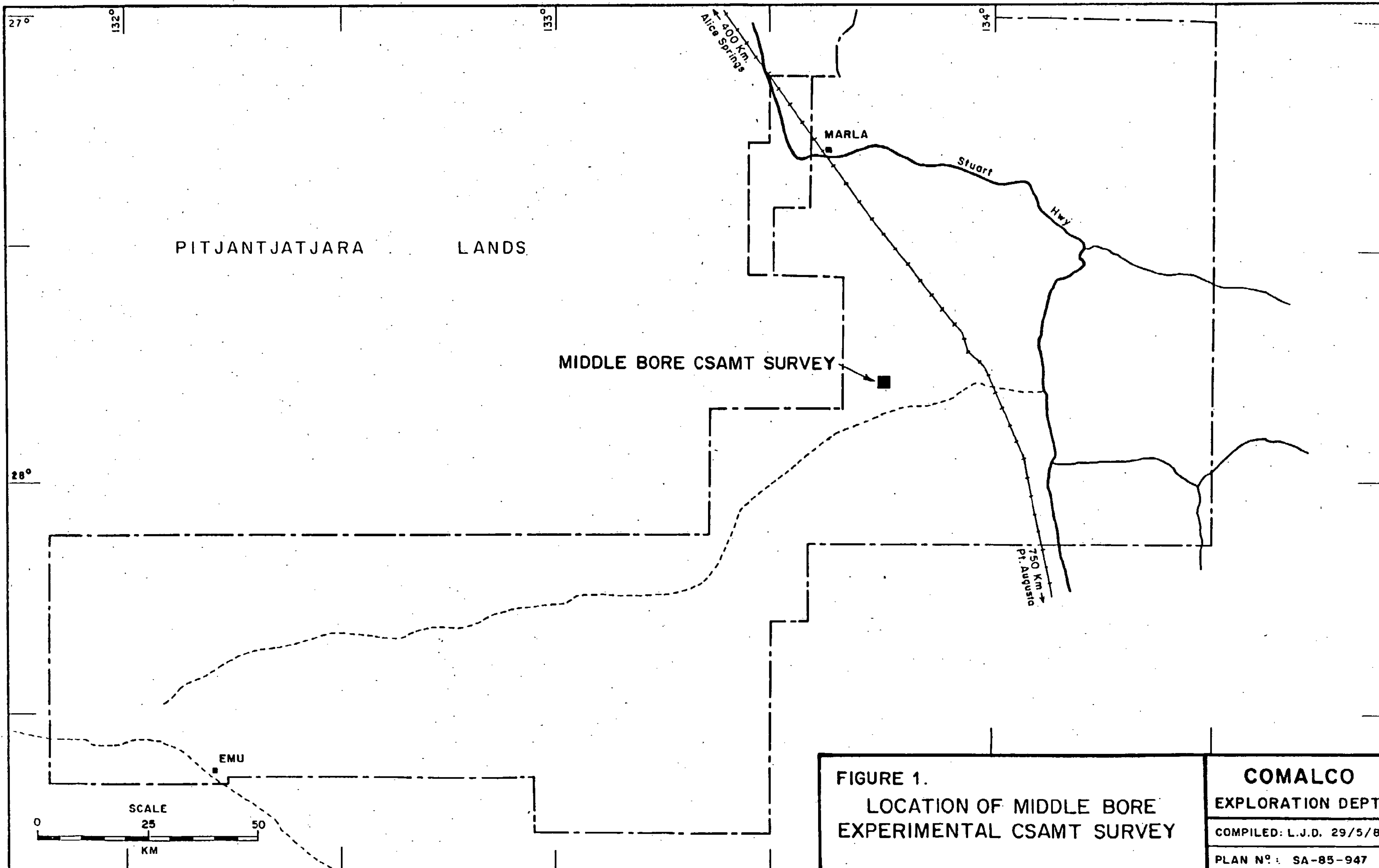

FIGURE 1.
LOCATION OF MIDDLE BORE
EXPERIMENTAL CSAMT SURVEY

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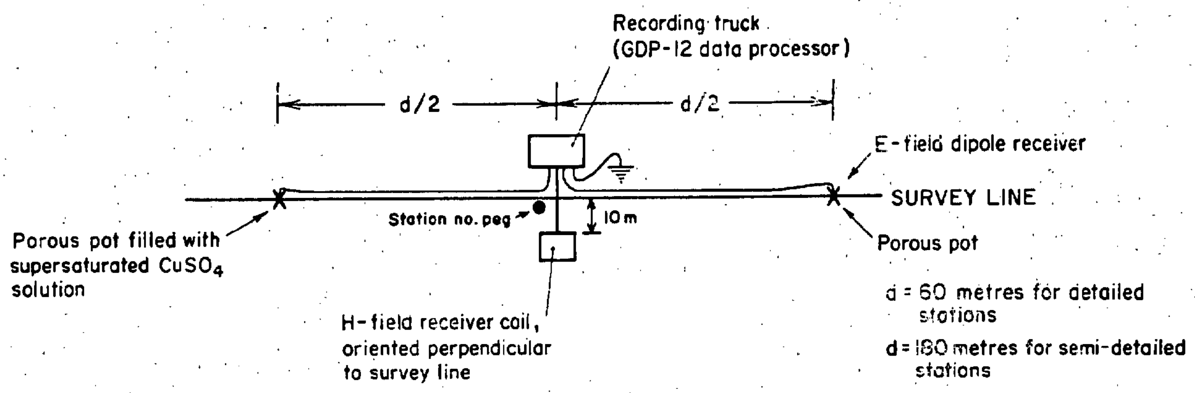
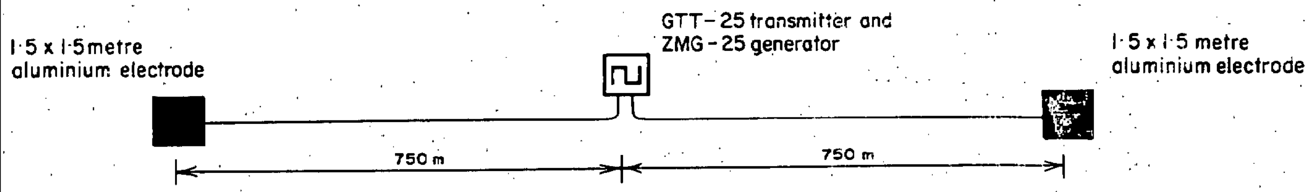
PLAN Nº: SA-85-947

1400

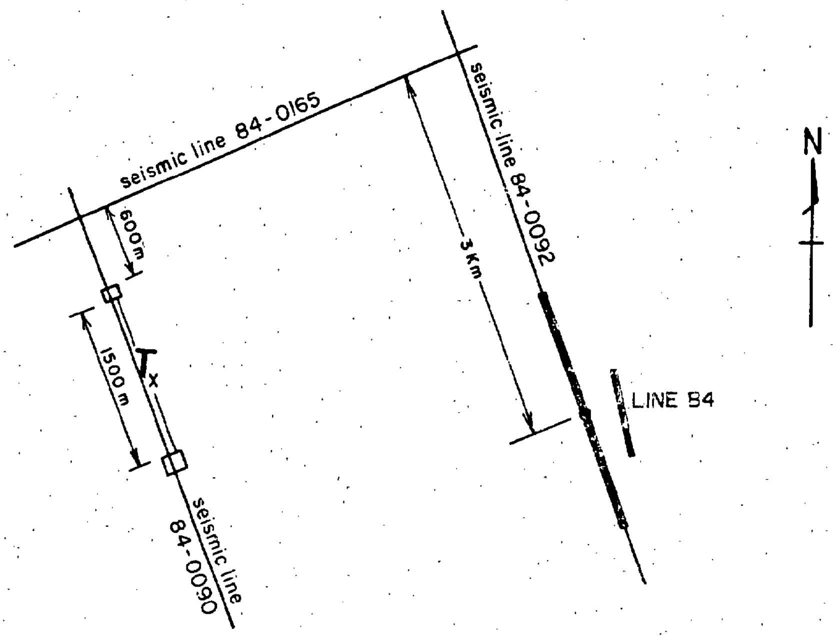
RECEIVER LAYOUT :



TRANSMITTER LAYOUT :



SURVEY PLAN :



NOT TO SCALE

FIGURE 3.

MIDDLE BORE EXPERIMENTAL CSAMT SURVEY LAYOUT PLANS

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DRAWN: J.E.Harrison 3/6/1985

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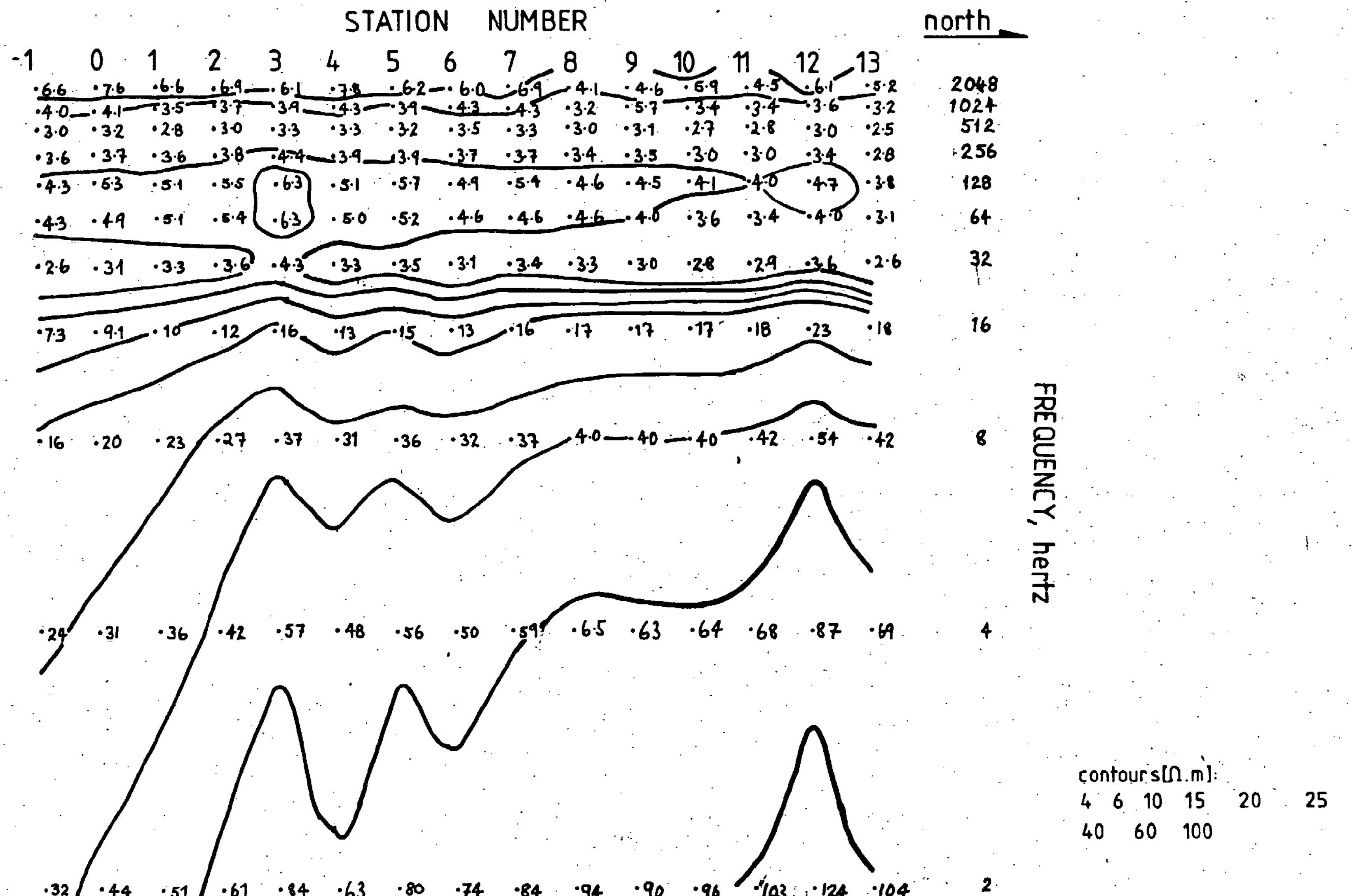

1401

120 0 120 240 360m

SCALE:
1:6000 horizontal

Figure 4 CSAMT DATA
apparent resistivity
LINE B4

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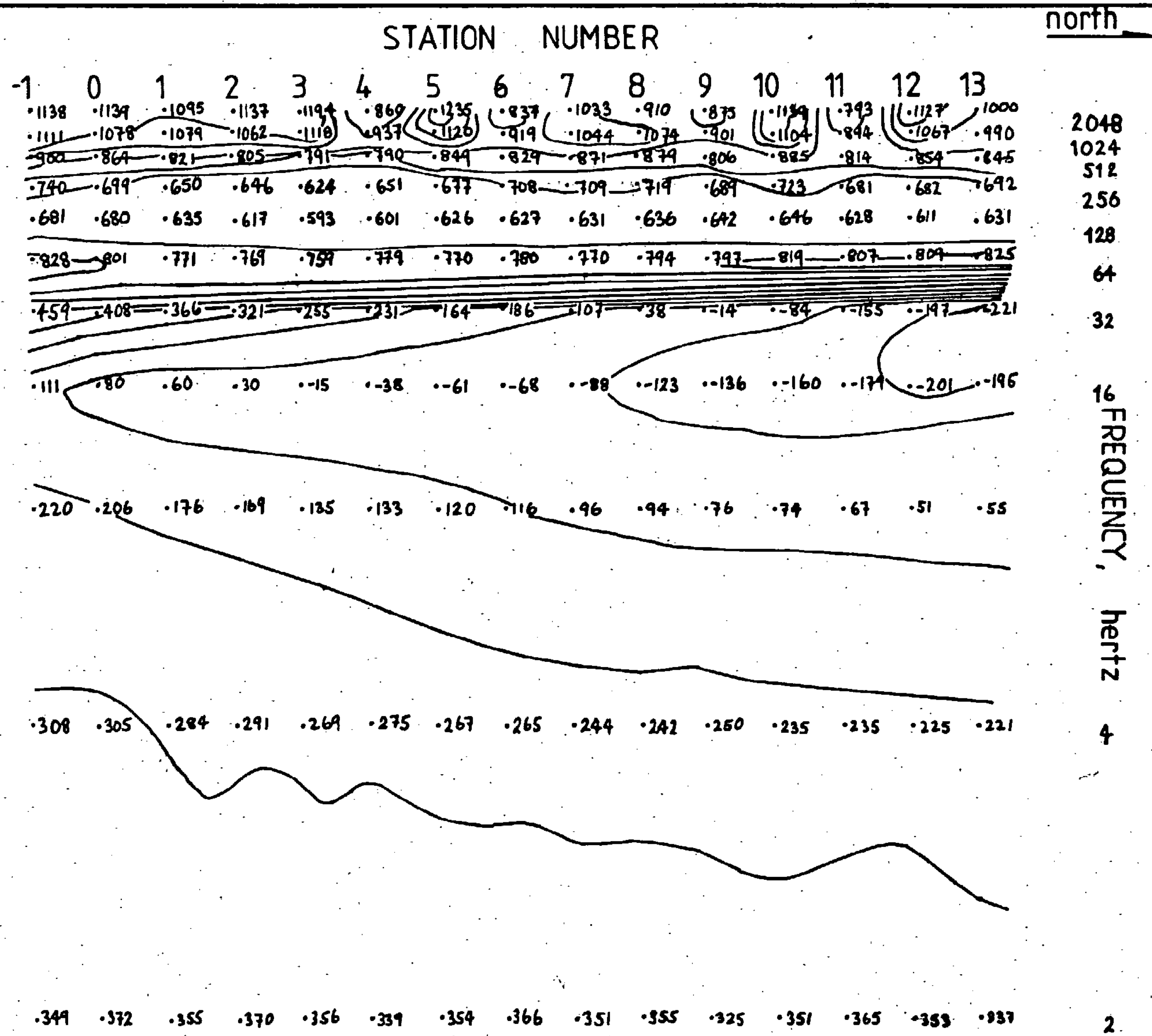
1402



units: milliradians (m^e)

c.i. 100 m^e

120 0 120 240 360m

SCALE:
1:6000 horizontal

Figure 5 CSAMT DATA
Δ phase
LINE B4

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