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Magnetotelluric Fieldwork

Preliminary report

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VARNET Project 1995 Magnetotelluric Fieldwork

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Abstract

Magnetotelluric fieldwork was carried out in southwest Ireland during the summer of 1995 as part of the Integrated Studies of the Variscan Front, VARNET. Participants from GeoForschungZentrum Potsdam, University College Galway, and the University of Edinburgh took part. This preliminary report has been produced to outline the current information relating to the dataset, before any large scale processing or development has taken place. A brief description of the magnetotelluric (MT) method is given, and previous MT work done in the area is referred to.

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1 A Brief Introduction to Magnetotellurics

A brief description of the magnetotelluric method is given here to describe the MT part of the VARNET project. Magnetotellurics is a geophysical method that uses the Earth's natural alternating magnetic field sources to construct models of geological structures based on their ability to conduct electricity. Introduced by Cagniard [3] and Tikhonov [18], the method is now well established and the literature is extensive. The electrical currents that are generated in underground structures are caused by a number of natural sources [16].

1. Regular daily variations (with periods of 0.2 to 1 day)
2. Disturbances including magnetic storms and their low frequency components (with periods of a fraction of an hour to 11 years)
3. Pulsations (periods 0.2 to 1000 seconds)
4. Atmospherics (with periods 0.0001 to 0.2 seconds)

Further electromagnetic fields at frequencies less than 1 Hz have their origins in interactions between the ionosphere and the solar wind. Charged particles from the sun interacting with the Earth's magnetic field generate secondary effects: geomagnetic pulsations [11]. These sources result in a collection of alternating magnetic fields which can be assumed to form a vertically incident plane wave [10] [13] [4]. The waves induce currents, with associated alternating electric fields. The fields can be detected and recorded using various MT equipment [19] [14]. The behaviour of the fields are described by Maxwell's Equations of Electromagnetism for a conductor with no free electrical charges [8], which relate magnetic and electric fields with electrical resistivity, allowing spatial models of electrical resistivity to be made.

$$\nabla.\vec{E} = 0 \tag{1}$$

$$\nabla.\vec{B} = 0 \tag{2}$$

$$\nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t} \tag{3}$$

$$\nabla \times \vec{B} = \mu \left(\sigma \vec{E} + \epsilon \frac{\partial \vec{E}}{\partial t} \right) \quad (4)$$

where $\vec{B}$ is a magnetic induction vector due to the sources, $\vec{E}$ is a resultant electric field vector, σ is the electrical conductivity of the excited medium, μ is the permeability and ϵ is the permittivity. The literature on this topic is very extensive, but those interested are referred to one of the clearest expositions of the subject [2]. Spatial models of electrical resistivity are very important in describing the geology, as structures of different types, origins and histories have distinct electrical resistivities. A typical range of resistivities of Earth materials is shown in Figure 1 [12].

2 Resistivity in the Southwest of Ireland

In southwest Ireland, the region of study, it is expected that the most electrically resistive features will be consolidated sediments such as the Old Red Sandstone and limestone [2] and that a granite body suggested by gravity studies [5] would have a lower resistivity. The formation of graphite, a very good electrical conductor, may also yield strong signatures, as has been noted in other similar examples [1]. Major faults, for example the Killarney-Mallow fault, would have conductive fluids and/or mineralisation resulting again in lower resistivity. Some results suggest a northern boundary to the Munster Basin [2] and the presence of other faults and structures in this way. Figure 2 [2] shows a typical model in the southwest of Ireland taken along a NNE-SSW line with a clear contrast between the southern Old Red Sandstone and the more northern Carboniferous limestone.

3 Fieldwork in SW Ireland during 1995

A team consisting of scientists from GFZ Potsdam, University College Galway and the University of Edinburgh worked in the southwest of Ireland during the summer of 1995 to select, set up and maintain a series of MT sites. The locations of the sites can be seen in Figure 3 on a map of the southwest Munster area.

Three major types of instruments were used :

1. LMT: Long Period Magnetotelluric device, an instrument which was used to record data in the range 0.1 seconds to fractions of a year. Three of these were used and placed at sites RAT, CLYD and ROC (see site map), and will be left there until December 1995. They will provide information on the mid to lower crustal structure.

2. KMT: The KMT is typically used in the several Hz to 4000 second range. It has the ability to resolve near surface inhomogineities, such as major faults.

3. SPAM3: The Short Period Automatic Magnetotelluric device, developed in the University of Edinburgh [14] [15] , is currently the most advanced instrument of its type. In Ireland, it was used in the range from about 2 kHz to 4000 s, although its capabilities extend beyond these ranges. It is a very powerful tool because not only does it allow this range of periods, but it offers real time data analysis, some of which is shown in the included diagrams. This gives immediate results from a site, allowing the user to decide if the site is good for the collection of data or not.

Some of the sites were chosen using SPAM, resulting in a high quality of data collection. The sites were set up in an array with many simultaneous measurements taking place across the grid. Five of the sites, RAT, MIL, CEC, SHA and AIR coincide with a proposed seismic line. A much greater number of sites were set up than originally proposed. Also, the simultaneity of the data collection allows a large proportion of noise to be removed using powerful techniques e.g. [6].

4 Previous MT work in SW Ireland

The Ph.D. work of Paul Bruton. A series of magnetotelluric profiles were made in the south west of Ireland by Bruton [2] (see Figure 4). Among the many developments that he made in his extensive work Bruton produced the following results:

1. The Clare Shale Formation was found as a sub-horizontal conductor in the short-period models of the northern section of the eastern profile.
2. A robust feature which appeared in all models beneath the site HERL was interpreted as being related to a break in the shale layer.
3. A resistivity contrast was found between the regions north and south of the surface expression of the Killarney-Mallow Fault, in the short-period models of the centre section and in a long-period model of the eastern profile.
4. A conductive feature beneath the site HERL may coincide with a proposed northern margin to the Munster Basin, i.e. the Dingle Bay - Galtee fault zone, though the data quality in this area may not be good enough to be conclusive.

He also suggested that work done on more than one profile should involve simultaneous recordings at a pair of sites on different profiles. During the course of the VARNET MT experiment in Ireland, there were periods during which up to 7 devices across the array were running simultaneously.

5 Work done on the data set

Filtering and analysis has begun on the VARNET MT dataset. The work done so far on the data can be described as follows:

1. SPAM data
   (a) Initial impedance and phase diagrams have been produced which allow a basic insight into the nature of the structures detected by SPAM (see Figure 5 for an example from site ROC).
   (b) Further cleaning of the data has been carried out.
2. KMT data
   (a) Creation of time series plots to select good data segments at each of the sites (see Figure 6 for an example from site CEC).
   (b) Development of the software [7] required to clean and present the data for further processing.

3. LMT data
    (a) This dataset is not yet available.

6 Proposed work on the data set

There will be integration with previous seismic, electromagnetic, gravity, MT and geological interpretations, e.g. [17].

7 Acknowledgements

We are grateful to the other fieldworkers in Ireland such as Gareth Armstrong, Karsten Bahr, Grace Canny, Markus Eisel, Markus Himmerich, Sebastian Hőlz, Kevin O'Callaghan, Oliver Ritter, Fiona Simpson and Wolfgang Soyer, to the local people in the southwest of Ireland for their assistance and hospitality and for the help of Stefan Friedel and Dr. E. Ritter.

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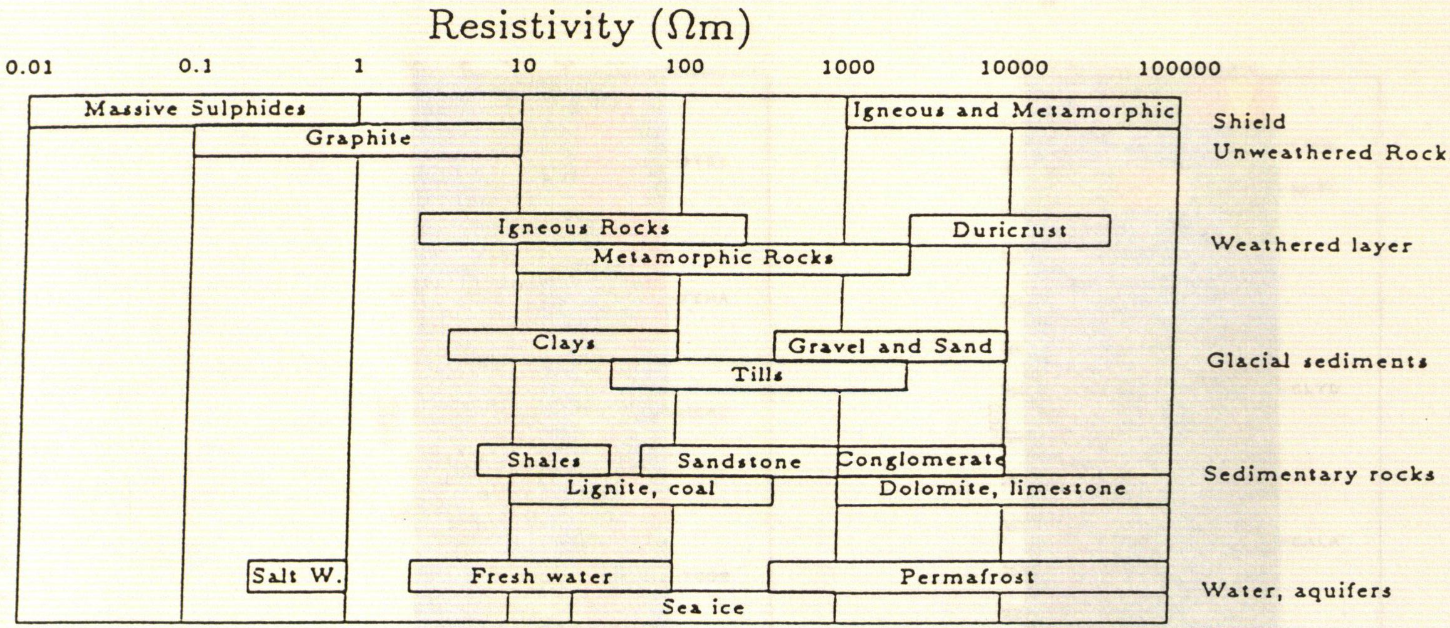

Fig. 1 : A typical range of resistivities of the Earths material [13]

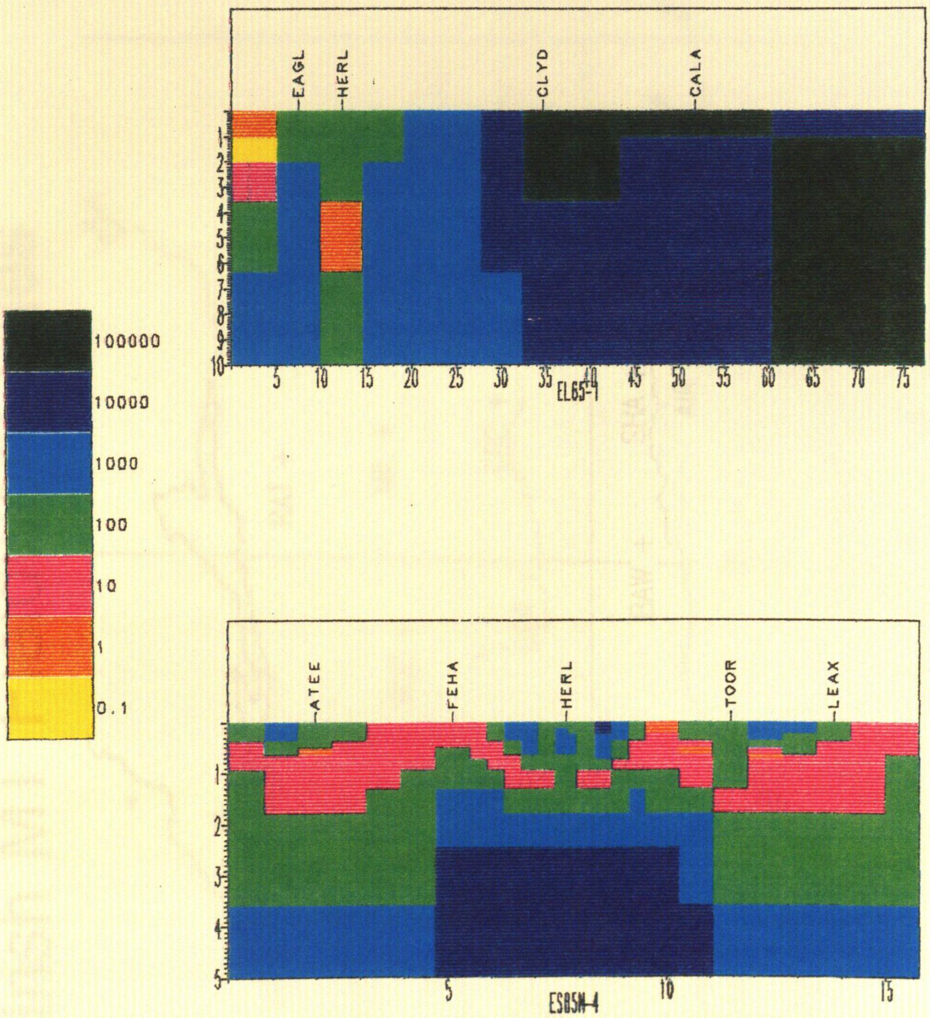

Fig. 2 : Two models taken along profiles in SW Ireland [2]. Models dimensions are in kilometres and electrical resistivities in ohmmetres, indicating the centre of a decade.

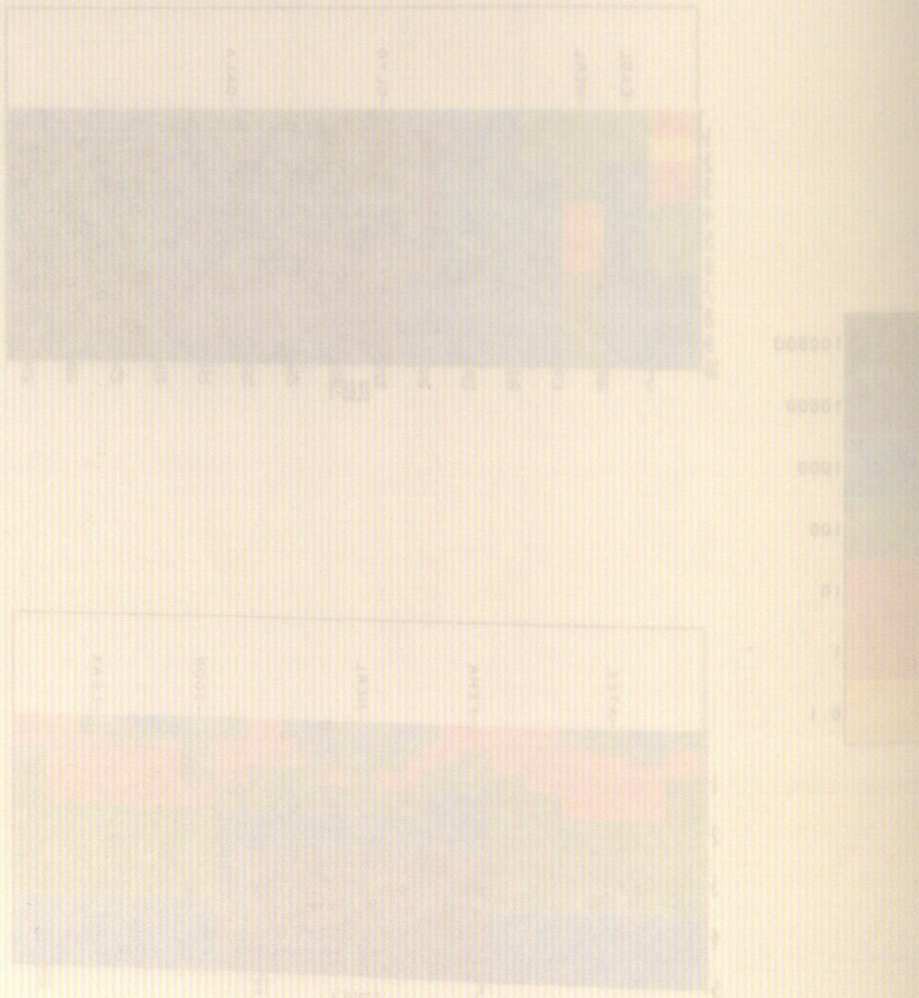

Fig 2.1 Two models taken along profiles in SW Iceland [3]. Models dimensions are in kilometres and electrical resistivities in ohmmetres, indicating the centre of a decade.

VARNET '95
Irish MT Fieldwork Sites

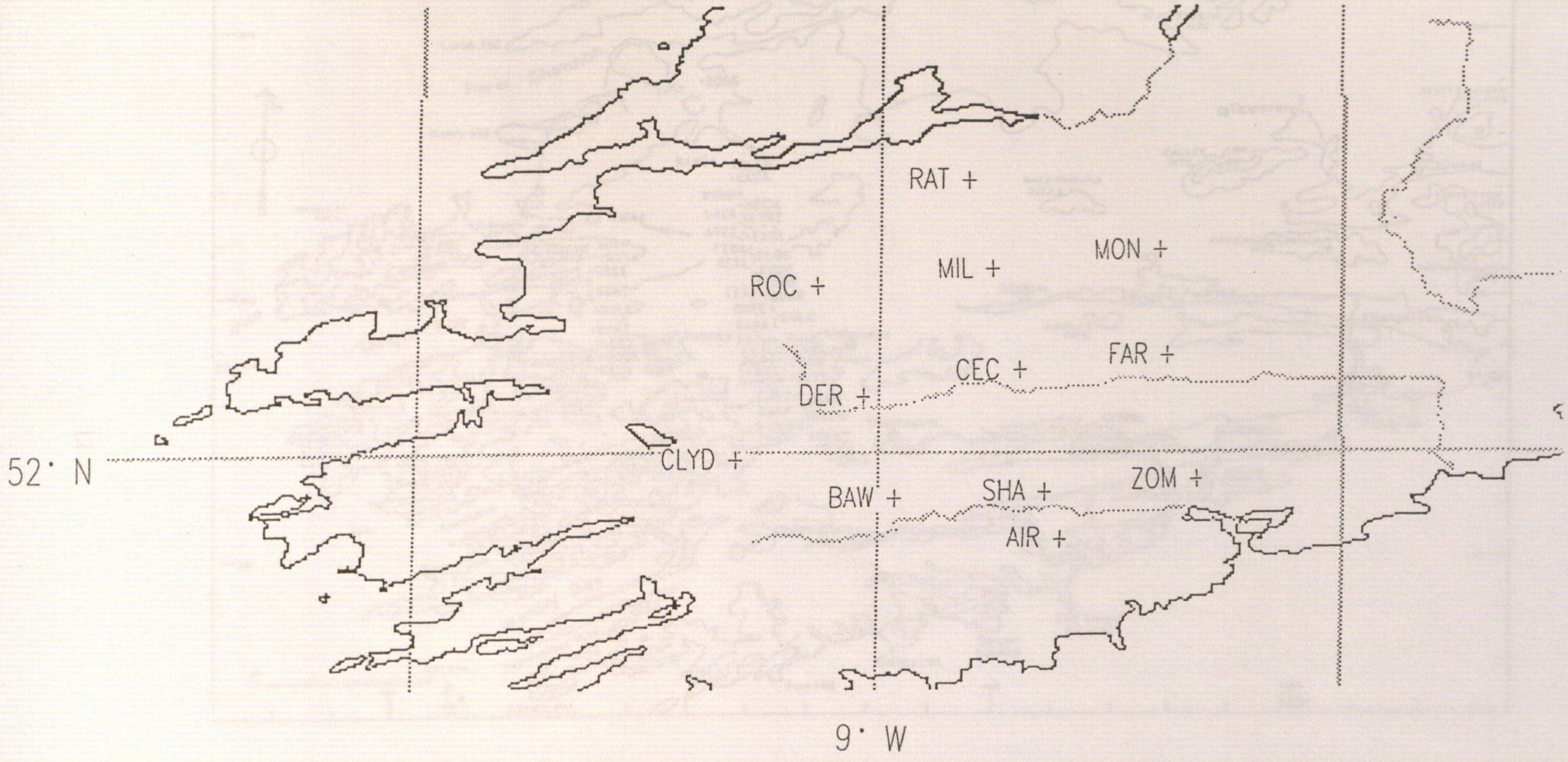

Fig. 3 : VARNET 1995 Irish MT Fieldwork Sites

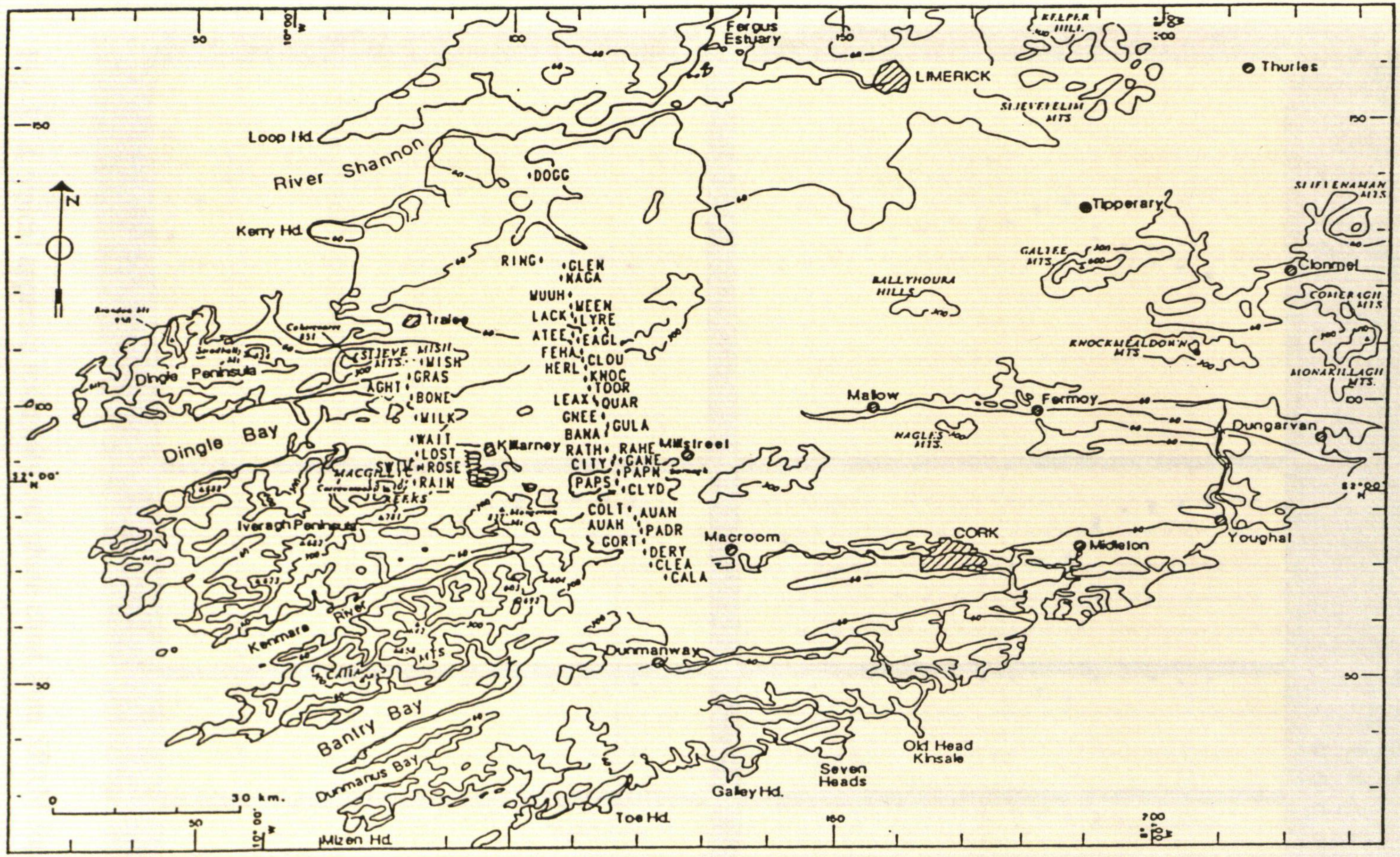

Fig. 4 : Site map for the MT fieldwork of Paul Bruton [2]

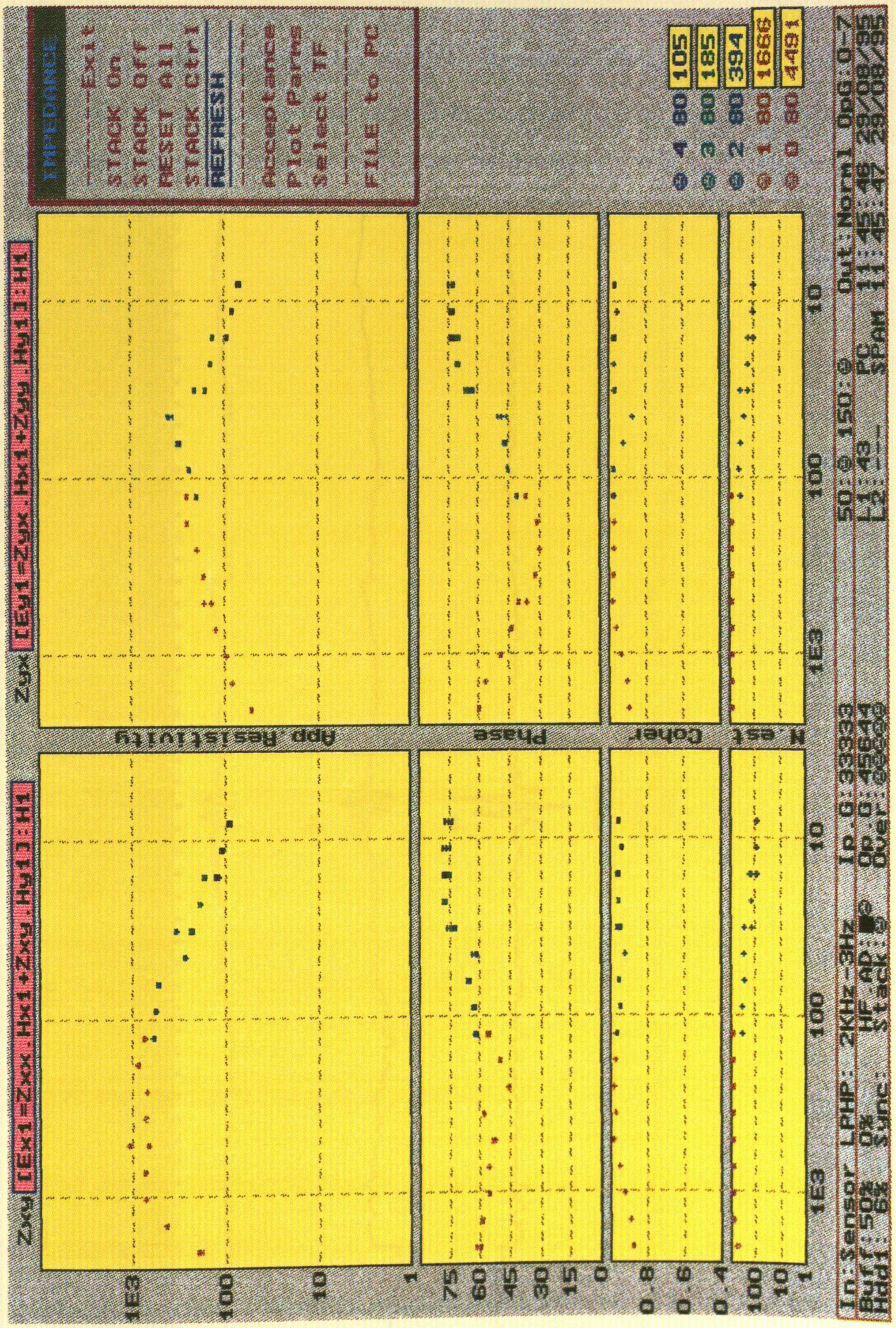

Fig. 5 : A typical apparent resistivity and phase chart from SPAM for site ROC

Fig. 6 : A typical time series from the KMT data of site CEC from VARNET MT 1995