Application of Joint Inversion Technique to Deep Resistivity and Magnetotelluric Sounding Data in Northumberland Basin, Northern England

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Application of Joint Inversion Technique to Deep Resistivity and Magnetotelluric Sounding Data in Northumberland Basin, Northern England

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Abstract

Deep resistivity sounding (DRS) and magnetotelluric sounding (MTS) techniques were applied to determine the thin resistive layers in Northumberland basin, Northern England. The results of ridge regression inversion of deep resistivity data, linearised inversion of magnetotelluric data and the joint inversion of DRS–MTS data sets are presented. By comparison with the borehole information, joint inversion results are found to be useful in locating the thin resistive formation in this region, which could have not been possible with application of either one of the methods individually.

INTRODUCTION

It is well known that the purpose of modeling the electrical/electromagnetic data using inversion schemes is to derive a conductivity parameter at the subsurface of the earth that satisfies the observed data. Inferences can then be made about the nature and extent of the structure with respect to the geology of the area. However, due to inherent difficulties of inversion schemes and data errors, it is not possible to obtain an unique solution and a set of models can explain the observed data. In order to reduce the ambiguities of derived models using data from any single geophysical measurement, joint inversion/interpretation schemes (Vozoff and Jupp, 1975; Raiche et al. 1985; Ritz and Vassal, 1986) have been developed. In these schemes the data from two or more geophysical measurements are considered.

Apart from the problem of obtaining unique solution for a general earth model, the detection of a thin layer poses more problems with the data from a single electrical or electromagnetic method. The detectability of a thin layer has been studied earlier by several workers in electrical and electromagnetic methods and also in magnetotelluric (MT) method (Verma and Mallick, 1979; Rakesh Kumar et al. 1981 etc.). It is known that the magnetotelluric method can more easily detect a thin conducting layer than a resistive one. Resistivity sounding methods are, however, equally responsive in both these situations, but longitudinal conductance is usually more resolvable for thin conductive layers and transverse resistance is more resolvable for thin resistive layers.

In the present paper an attempt has been made for the application of joint inversion scheme (Vozoff and Jupp, 1975) to detect thin resistive layers. For this purpose DRS and MTS data from Northern England region have been considered. Fortunately, the borehole log information is also available for a comparison of the results.

GENERAL GEOLOGY AND THE DATA

The region around Northern England is mostly covered with Carboniferous sediments formed in a trough — the Northumberland trough — known as a major east-west structural unit bounded by the Alston block in the south and the Southern Upland block in the north (Fig. 1). The sediments in this region consist mostly of sandstones and mudstones, which are conducting formations, interbedded by comparatively resistive limestone formations. The high resistive granitic basement is concealed below the sediments. The intrusive rocks in the Carboniferous strata consist of several sills and dykes, the important intrusion being the high resistive Great Whin sill and its associated dykes (Johnson, 1984). Thus the subsurface consists of conducting formations interbedded by two resistive thin formations — the Great Limestone and the Great Whin sill — with a high resistivity basement, Weardale Granite Batholith.

In this region a series of DRS data had previously been acquired by the Earth Sciences department of Leeds University as a part of several M. Sc., projects and later compiled in a Ph. D. thesis (Roxis, 1984). These soundings were carried out along an approximately NS traverse covering Northern England and Southern Scotland with a square array configuration and electrode spacing at most stations up to 1024 m. The spacing was extended further using bipole-bipole measurements. In the present study, the equivalent Schlumberger electrode spacings have been considered as described by Habberjam and Thanassoulas (1979). Magnetotelluric soundings (100–0.01 Hz.) have been carried out (Harinarayana, 1988) along a 140 km profile across Southern Scotland and Northern England. Three of the MT stations — Lampert (LAM), Edges Green (EDG) and Rookhope (ROO) — were located in close vicinity (1–2 km) to DRS stations. The elevation differences are small (10–20 m) and the geology is uniform between DRS and MTS stations. Thus, these data sets can be considered for joint inversion scheme to resolve thin layers in this region.

Before considering the datasets for the joint inversion scheme it is necessary that the depth range over information which can be obtained from either (the DRS and MTS) data sets should have adequate overlap. In the

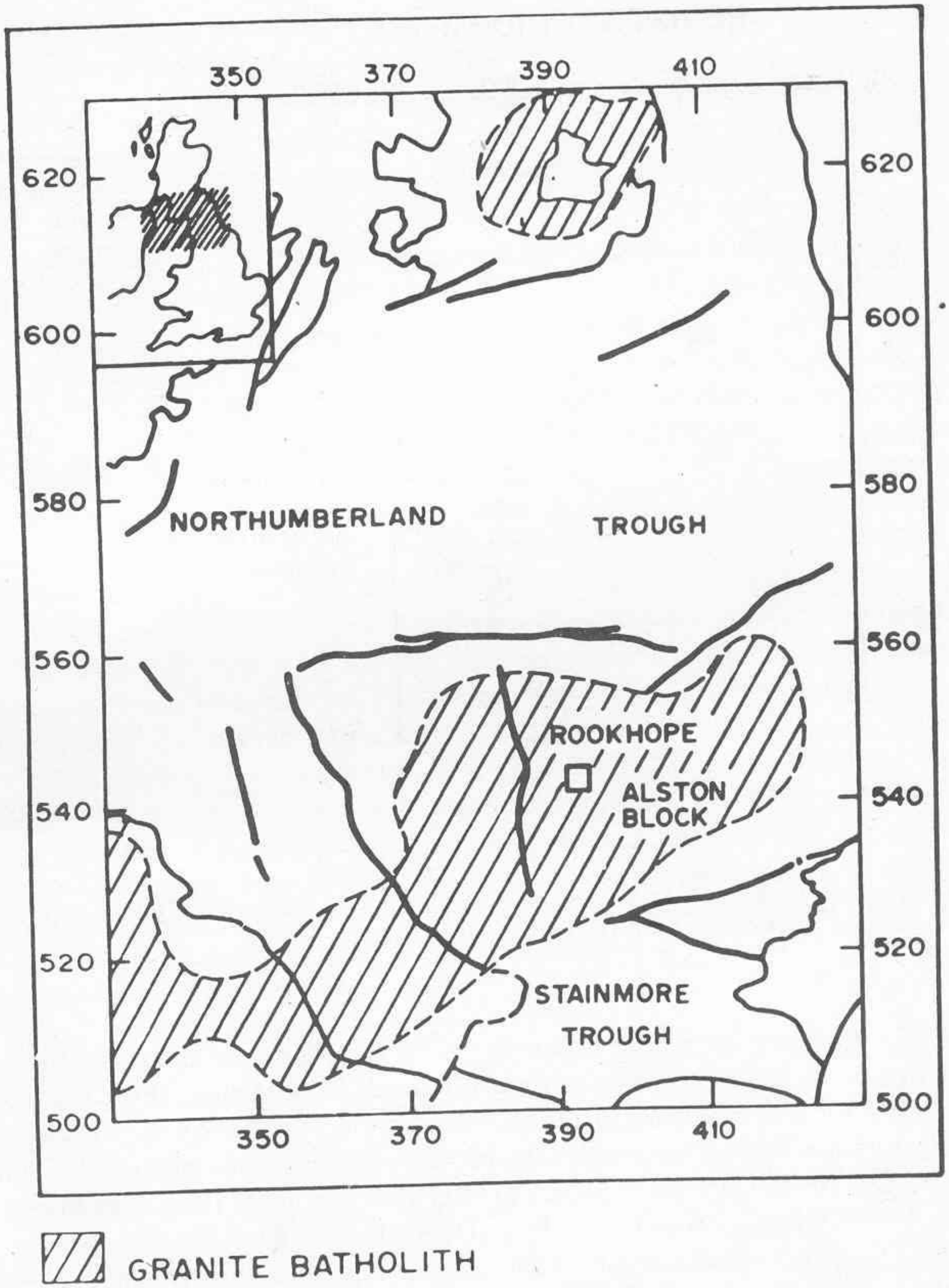

Figure 1. General geology of the area and MTS site (Rookhope) location. Shading indicates the region underlain by Granite Batholith.

present study the data at two locations — LAM and EDG — the maximum depth to which information can be obtained from the DRS data (Roxis, 1984) hardly overlaps with that which can be obtained from the MTS data. However, there is a good overlap of resistivity information between DRS station S1 and MTS station — ROO — located near Rookhope (Fig. 2). Moreover, very near to

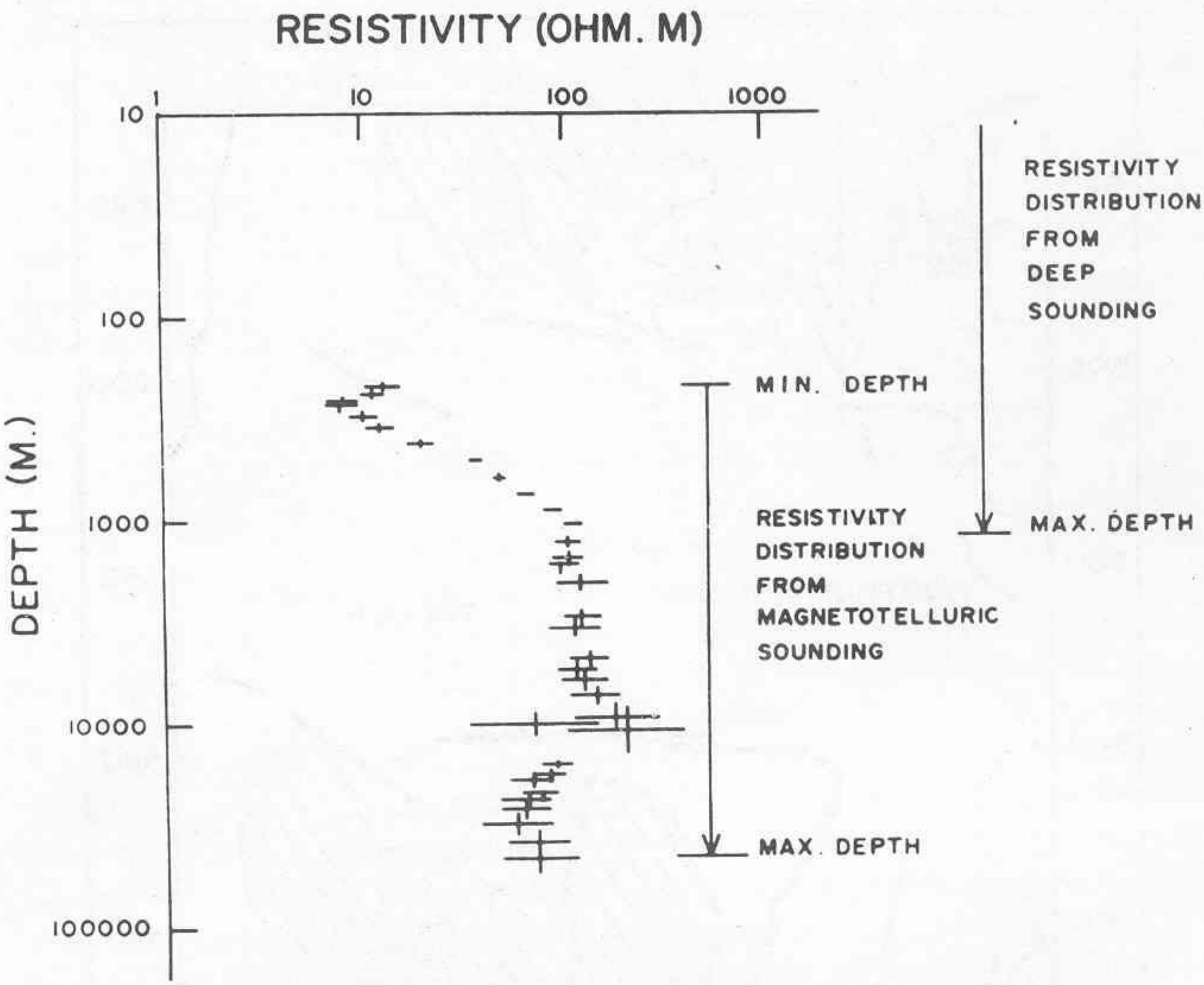

Figure 2. Plot of resistivity as a function of depth showing the depth of information that can be obtained individually from DRS data and MTS data.

the ROO station, a deep bore hole was drilled to a depth of about 795 m and resistivity, S. P. and γ-ray logging data obtained. This station, thus, provides useful data for a comparison of results. In addition, this station is particularly significant from the geophysical point of view. The presence of the Weardale Granite was predicted from Bouguer gravity (low) anomaly (Bott and Masson Smith, 1957) and later proved by drilling (Dunham et al. 1965). At this location a number of earlier geoelectrical measurements had also been made and the resistivity models correlated with the borehole data (Habberjam and Thanassoulas, 1979; Novak, 1981 and Roxis, 1984). For example, Habberjam and Thanassoulas (1979) obtained reasonable agreement between computed and observed data when they used a model with the resistivity values and the thicknesses of the Great Limestone and Whin sill fixed to correspond with those of the borehole. Constraining the bottom layer resistivity at 1500 Ohm. m, 1053 m depth has been obtained for the Weardale Granite from the ridge estimates for the DRS data (Roxis, 1984). Constraining the depths by bore hole data and allowing the resistivity values to vary a good fit to AMT observations has been shown by Novak (1981).

RESULTS AND DISCUSSION

The data sets for both the DRS and MTS stations have been acquired in two perpendicular directions, but in the joint inversion the square array apparent resistivity has been considered as Schlumberger resistivity for the DRS data and rotationally invariant resistivity and phase (Ranganayaki, 1984) for the MTS data. Since the parameters of the deepest layer (at about 4–5 km) obtained from the MTS data cannot influence the DRS data, these parameters were held fixed during the inversion.

It is not difficult to construct a model based on the bore hole information and compute the response that fit closely with the observed values of MTS and DRS data. However, in the present study the object was to approach the joint inversion problem with a priori information and then compare the resulting model with the borehole resistivity log. The initial models chosen for the joint inversion were obtained by combining the model results of the individual methods.

The observed and computed data for DRS and MTS using joint inversion are shown in Fig. 3. The results obtained from the inversion of DRS (ridge regression) by Roxis (1984), MTS and combined DRS–MTS datasets of the present study are given in Table I and the resistivity distribution as a function of depth is shown in Fig. 4. All these results are summarised and presented in Fig. 5 together with the superposed borehole stratigraphy.

TABLE I Details of inversion results DRS, MTS and DRS-MTS datasets. Depths shown are to the bottom of each layer

DRS		MTS		MTS-DRS	
Ress. Ohm. m.	Depth m.	Resis. Ohm. m.	Depth m.	Resis. Ohm. m.	Depth m.
385	.8	81	154	389	0.6
1320	7.9	7	390	1338	6.5
87	22	1129	4618	70	18
308	75	70	****	561	42
76	166			32	78
3010	391			9161	147
71	1053			8	418
1500	****			1359	4618
				111	****

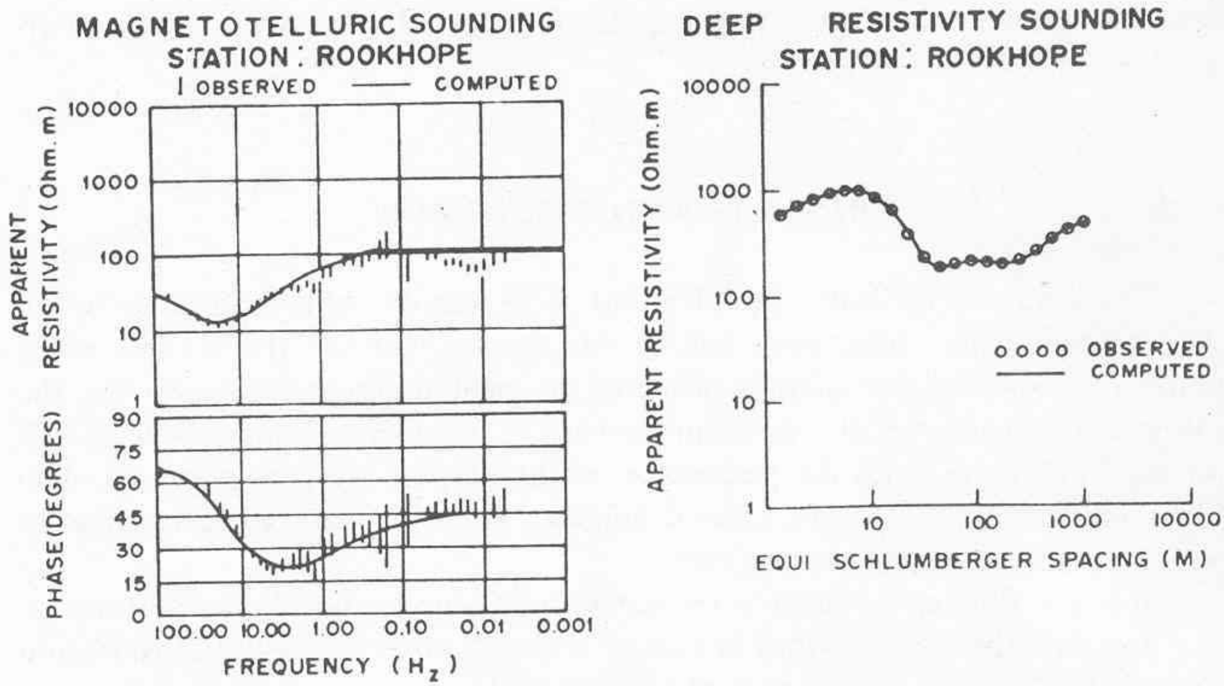

Figure 3. Joint inversion results of magnetotelluric and DRS data at Roo station, near Rookhope showing both the observed and computed data.

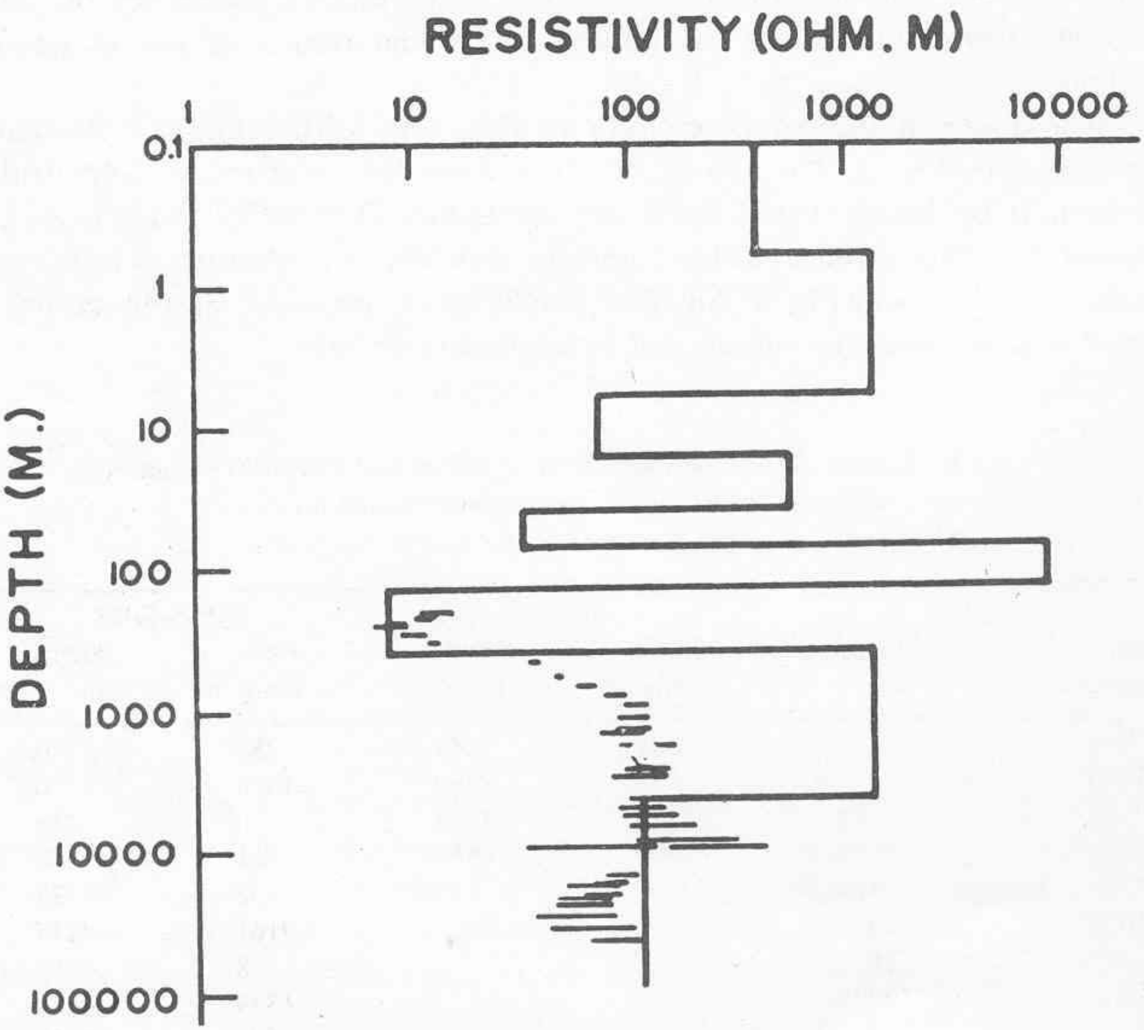

Figure 4. Model obtained from MTS as well as DRS data using joint inversion scheme.

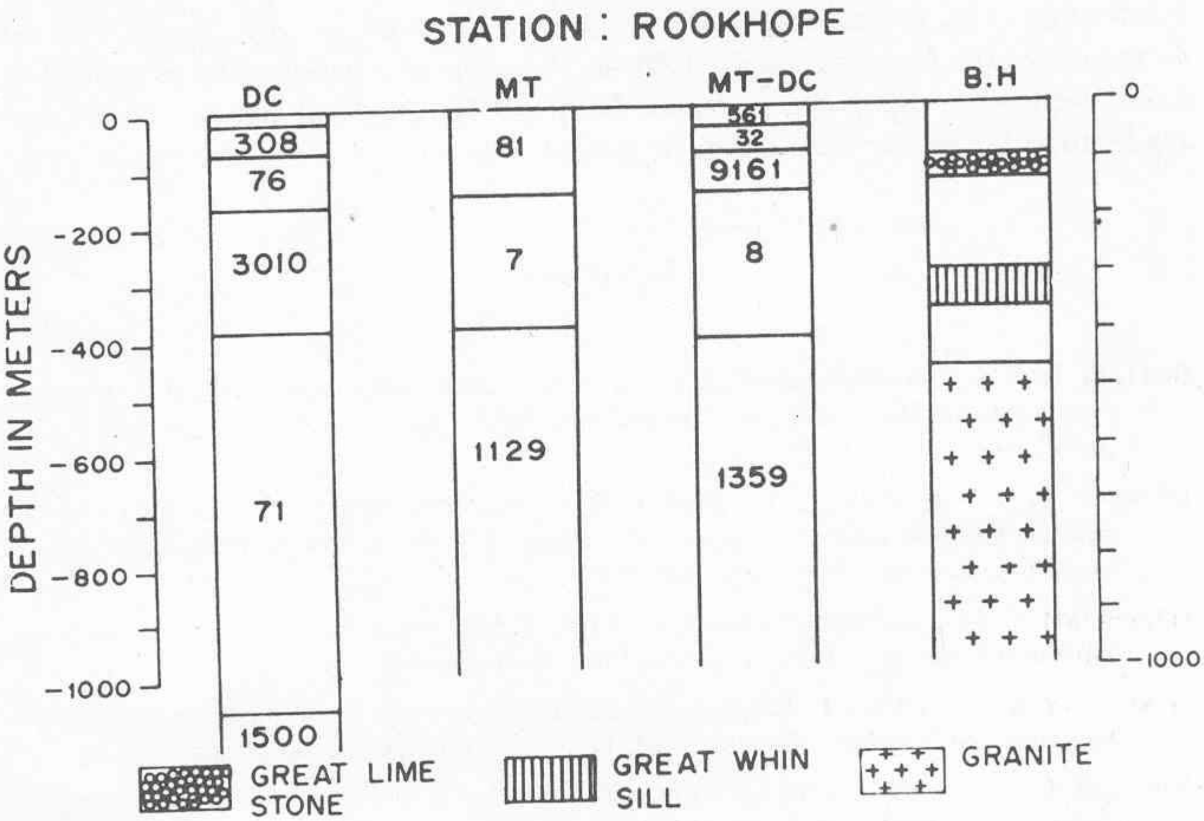

Figure 5. Comparison of the models obtained from DRS (Shown under column DC) magnetotelluric (MT) and joint inversion of DRS–MTS (MT–DC) data along with the borehole data at Rookhope. Numbers shown represent the resistivity in Ohm.m.

It is clear from Fig. 5 that there are three prominent resistive layers at Rookhope — the Great Limestone, the Whin sill and the Weardale Granite. It can be observed that the electrical boundaries derived from DRS and MTS modeling results do not, in general, correspond to those of the borehole. However, good correspondance can be seen from the model derived from joint inversion scheme. For example, the shallow high resistive layer (the Great Limestone) and the depth to the resistive Weardale granite are well estimated. This could not have been possible with application of either one of them individually. However, the Whin sill could not be estimated even from joint inversion scheme, possibly due to a) the presence of shallow high resistive Great Limestone and b) the thickness of the Whin sill is very small compared to its depth of burial.

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