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ON THE USE OF THE VLF SIGNATURE IN GEOLOGICAL MAPPING[1]

A.C.R. KETELAAR[2], I. GIBERTI[3] & B. MENNE[3]

ABSTRACT

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One of the electromagnetic methods of geophysical prospecting is known as 'VLF'. The method is outlined in the introduction. The traditional use of VLF lies in the exploration for sulphide orebodies. We suggest that a VLF survey contains information about the geology in a wider sense and indicate ways of extracting that information by applying techniques borrowed from seismic data-processing. Unlike the large and expensive computers which are used in the seismic industry, for our application we only need 'pocket computers'.

INTRODUCTION

The VLF method is one of a wide range of electromagnetic techniques that are available to exploration geophysicists. The system consists of a battery-powered receiver which picks up the magnetic field from a distant radio transmitter. The transmitter may be any of half a dozen very powerful broadcast transmitters situated around the world, that transmit in the 'Very Low Frequency Band', running from 10 000 to 30 000 Hz. In western Europe, two popular transmitters are those known by their call signs as: NAA and GBR. Their locations and operating frequencies are: NAA: Cutler, State of Maine, USA, on 17.8 kHz and GBR: Rugby, Great Britain, on 16.0 kHz.

At a distance of several thousand kilometres, the radiowave at the receiver location has a well-defined geometry. A portable transistor radio used to receive the more traditional radio stations, demonstrates this nicely: it has to be oriented in a definite direction in order to give the best reception or, on the other hand, to eliminate an interfering station. The VLF receiver must be tuned to the station which has been selected for use. The instrument uses the magnetic component of the radiowave. This magnetic component propagates in a horizontal sense and perpendicular to the bearing to the transmitter. However, as the radiowave also travels in part through the ground, it will there excite induction currents which give rise to secondary phenomena which in turn interfere with the magnetic field generated by the transmitter. The net effect is that the measured magnetic field may be distorted in orientation and phase relative to the 'original' field. The receiver operator measures the tilt of the magnetic field in the vertical plane and a phase angle.

The intricacies of instrument operation and data-analysis are not explained here. It is worth noting, however, that a typical VLF receiver is reasonably cheap (a few thousand dollars) and that one field measurement can be done in a minute or so. A VLF field survey is therefore fast and cheap. The standard procedure is to run profiles along straight lines perpendicular to the suspected or known geological strike, taking measurements at regular intervals. For an optimum induction effect, the bearing to the transmitter should agree approximately with the strike direction and the transmitter station must therefore be selected with this requirement in mind.

The interpretation of a VLF survey is traditionally limited to outlining 'conducting zones'. This is based on recognising the characteristic anomaly of a (steeply) dipping plate-shaped conducting body: this anomaly is known from model experiments as well as mathematical analysis and it roughly resembles a single sine-wave. The plate-shaped conducting body could correspond to various geological features: a fault, a mineralised zone, an ore vein, etc. The size and exact shape of the measured anomaly is determined by the geometry of the structure (thickness, depth to the top, depth to the bottom, length along strike and spatial orientation) and by the electrical conductivity of the zone.

In addition there are features which more properly must be assigned to the geology in a wider sense: weathering and the morphology that goes with it. It is known also, though not yet quantifiable, that the terrain slope (which is one aspect of the morphology) affects the measured VLF profile. The measured tilt and phase are also affected by the local variation in depth of weathering and the local variation in electrical conductivity that goes with it.

Outside conducting zones these combined effects produce a VLF profile which looks erratic and which does not show a lineup of the major sine-waves which are associated with conducting zones. Weathering and geomorphology are of course related to rock-type and its chemical/physical properties and details of the VLF profile must therefore also be related to rock-type.

This report attempts to show that an analysis of the VLF

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[2] Instituut voor Aardwetenschappen, Universiteit Utrecht, Postbus 80021, 3508 TA Utrecht, The Netherlands.

[3] International Institute for Aerial Surveys and Earth Sciences (ITC), Kanaalweg 3, 2628 EB Delft, The Netherlands.

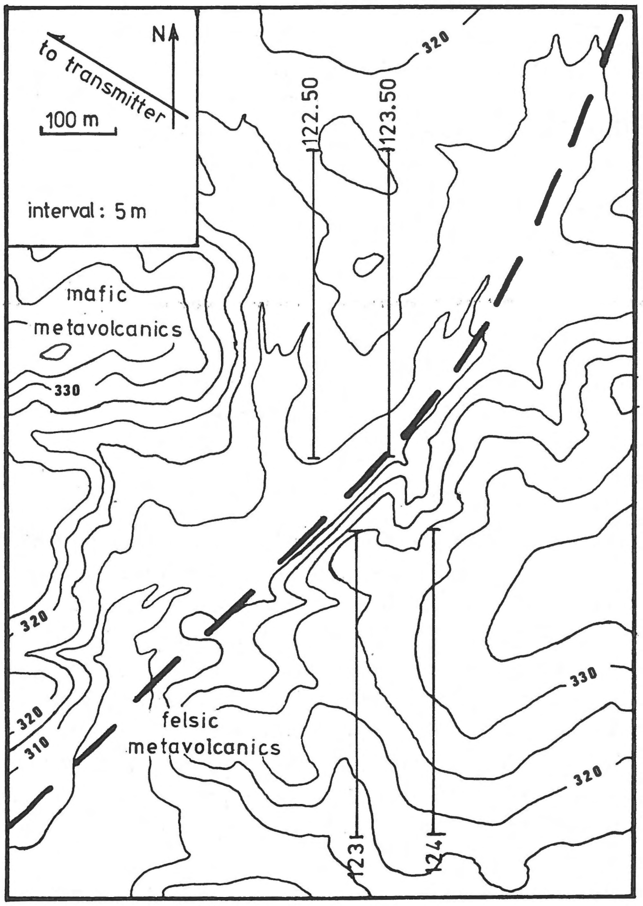

Fig. 1
Topographic/geological map of the investigated area.

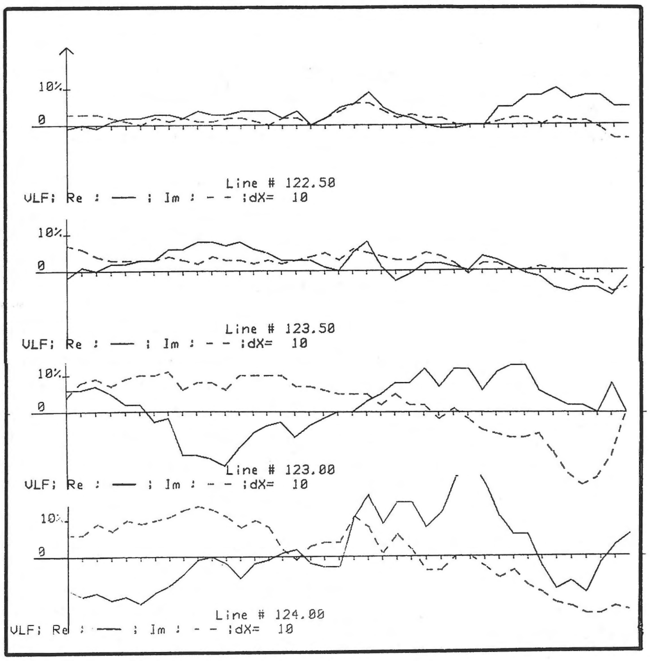

Fig. 2
VLF field profiles. Horizontal: distance. Vertical: Re and Im field components.

profile outside conducting zones can indeed provide geological information. One must simply consider the details in the VLF profile as part of the 'VLF signature' of that rock-type. This VLF signature can be analysed by techniques borrowed from seismic data-processing. Two have been tried: Fourier analysis and cross-correlation. A great help in these calculations is the availability of portable, battery-operated computing equipment. Machines of this type are justifiably called pocket or brief-case computers. They are programmable in BASIC, have a memory of several kilobytes, and can be connected to additional devices such as printers, graph-plotters and magnetic-tape cassette recorders. The use of this computing equipment matches the fast and cheap VLF field operation because it will typically cost a few hundred dollars and can be taken into the field office for speedy processing of the day's profiles. The system we used is decribed in the appendix.

THE VLF SURVEY

Fig. 1 shows the topographic map of a part of an area in which a VLF survey was conducted. The four marked profiles are perpendicular to the general strike and have been selected specifically to show the principles outlined in the introduction, without the complications of mineralised zones or formation boundaries. The orientation to the transmitter (NAA in northern USA) is shown: it is not perfect but usable. The ground resistivity is known to be about 300 ohmmeter, ranging from 200 to 400. The skin depth is 50 to 75 m ('skin depth' roughly expresses the effective penetration of the radio-wave into the ground, depending upon both the frequency and the ground resistivity)

The VLF profiles are shown in Fig. 2. The VLF response is read for two different quantities: Re = tilt of the major magnetic vector and Im = a phase angle related indirectly to the phase shift between the primary (transmitter) field and the secondary field originating in the ground. (Re and Im stand for Real and Imaginary, they may also be called Tilt and Quadrature). Both quantities are recorded in dimensionless percentages. The station spacing is 10 m.

GEOLOGICAL SETTING

Fig. 1 shows the distribution of rock-types. In part they are only suspected and the dividing line has been inferred on the basis of the morphology.

The problem involved geological mapping in a volcano-sedimentary environment: the Pyrite Belt in southern Spain. For reasons of confidentiality the locality can not be specified. It is known (STRAUSS ET AL., 1977) that the massive sulphide deposits in this province are associated with felsic metavolcanics. In the area under study these rocks could not easily be identified in the field. A distinction between the metavolcanic sediments and other rocks was possible on the basis of electrical resistivity measurements, but no distinction was

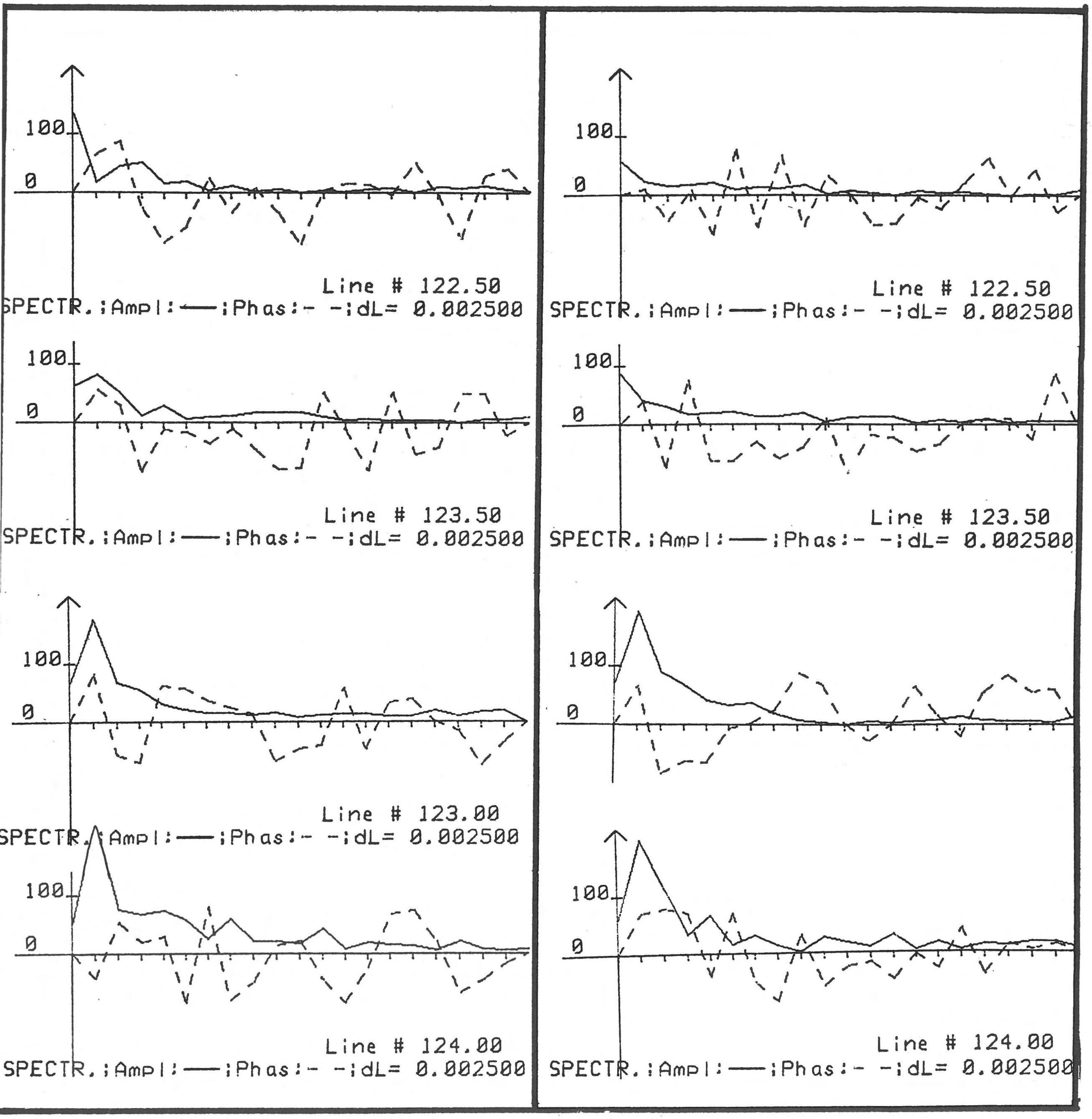

Fig. 3
Amplitude and phase spectra. Horizontal: frequency. Vertical: amplitude and phase.

possible on that basis between felsic and basic metavolcanics.

The two pairs of profiles (Fig. 2) showed decidedly different patterns. In part the differences in topography between the two areas can account for the different patterns, but as noted in the introduction too little is known about the effect of the topography to analyse it as such. The effect of the topography is lumped together with the effects of the variations in overburden thickness, depth of weathering and changes in conductivity to produce the final VLF profile. We attempted to express the different patterns in a quantitative form.

FOURIER ANALYSIS AND CROSS-CORRELATION

We took a cue from seismic signal analysis and subjected the VLF profiles to spectral analysis. This was done by a Discrete Fourier Transform (DFT), which is a mathematical operation by which a complicated waveform (such as a VLF profile) is separated into its constituent simple sine-waves expressed as frequencies: the frequency spectrum. In this case ‘frequency’ is understood to be the inverse of the wavelength: the correct designation is ‘spatial frequency’. The spectrum contains an amplitude part and a phase part. Fig. 3 shows the spectra of

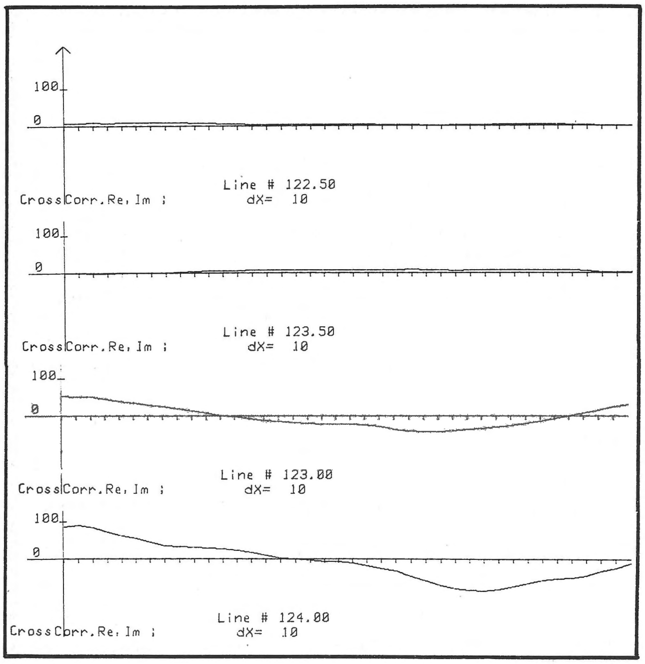

Fig. 4
Cross-correlation functions of Re and Im components. Horizontal: displacement. Vertical: amplitude.

the Re and the Im components of the four VLF profiles. It is noted that the two southern profiles show a broad high-frequency component and a major peak at a spatial frequency of 0.0025. The two pairs of profiles do show differences in their spectra but this is not obvious at a glance. For a full explanation of Fourier analysis and cross-correlation see BÅTH (1974).

A second approach was tried: cross-correlation between the Re and the Im components of each profile. Cross-correlation is a mathematical operation by which the similarity or parallelism between two complicated waveforms is measured: it includes a relative shift in space between the two waveforms in order to check for a possible displacement of one relative to the other.

The cross-correlation functions of each VLF profile are given in Fig. 4. The spatial shift limits mentioned above have been set at + and – 20 (half the total numer of samples on each profile). To avoid a decrease of the output towards both ends, the output has been normalised for the varying number of data-points involved in the calculations.

It would appear that the cross-correlation functions do show differences which are obvious at a glance. The similarity between lines 122.50 and 123.50 is striking. The very low values of the cross-correlation functions in these two profiles indicate that the Re and Im components in both show almost random fluctuations. Lines 123 and 124 agree very well with each other and, as a pair, are completely different from the other two.

Even though we cannot assign the individual differences to particular rock types, the reasoning given before seems to hold: the rock-type shows a characteristic 'VLF signature', which seems to lie in the Re and Im parts.

CONCLUSION

We have shown that, outside conducting zones, the VLF field profile shows a 'signature' which is recognisably different for different rock types. One way of analysing the signature is to calculate and plot the cross-correlation function of the Re and Im components of the VLF-profile.

The VLF instrument is cheap compared to much other geophysical equipment. The field procedure is fast and requires one operator. For the subsequent fast data processing and plotting cheap computing equipment is available.

We suggest that the system could be called on to help in some problems of geological mapping. We do not claim however, that presently a rock can be identified on the basis of its VLF profile. It would require further study before deciding whether that is possible at all.

APPENDIX

For efficient data-processing (including plotting) the following equipment is required: 1. computer, 2. magnetic tape recorder, 3. printer, 4. plotter.

The first three requirements are filled by many makes and types. The fourth requirement limits the choice to a few. We used the following system at a total cost of a fraction of the VLF receiver:

1. Sharp PC 1500, programmable in BASIC. The standard memory configuration has 2.8 kbytes of RAM (Random Access Memory), which is not really satisfactory. A plug-in memory module increases this to a satisfactory level. The computer runs on dry batteries. It is pocket-size.
2. Any dry-battery operated cassette recorder is satisfactory.

3.&4. Sharp CE 150, which is a combined printer and plotter with cassette interface. Actually the plotting pen is used to 'write' letters and numbers when used as a printer. The paper has an unlimited length and a plotting-width of 44 mm. For plotting a VLF profile an anomaly scale of 1 mm to 1% is customary, which allows anomalies up to 22% (positive and negative) to be plotted. The unit runs on rechargeable cells which allow a continuous plotting and printing cycle of 50 minutes. It will normally be used while plugged into the mains via the recharger. The unit is of brief case size.

The calculating and plotting times noted for one on the profiles (involving 40 stations with 2 measurements each), were:

1. plotting the VLF profile of both components: 1 min.
2. calculating the DFT of one component (Re or Im): 6 min.
3. plotting the DFT of one component: 1 min.
4. calculating the cross-correlation function: 1 min.
5. plotting the cross-correlation function: 1 min.

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