General Aspects of Geophysical Field Work

Preface

The acquisition of data is fundamental to geophysical investigations and 'real' data is only acquired in the field. Without real data no true practical conclusions can be made about a particular requirement.

These notes are largely the result of the author's 35 years of experience in exploration geophysics. Some of it is from bitter experience and it is best to heed the advice.
The notes are intended to apply in general only and to all types of field work including to environmental and engineering applications which can be different situations to other exploration activities. These differences are outlined in Section 2.

The remarks refer to ground surface surveying only and not to the particular operations of airborne, marine or underground surveys. The special use of instruments mounted on mobile platforms is also not dealt with.

Detailed discussions of the theory of individual methods, the operation of specific instruments, the presentation of results and their interpretation are also not included.

1. The Environment

The 'outdoors' is very different to a laboratory as a place to try and make accurate measurements. As for operator comfort, it can be too hot, too cold, raining, blowing a gale and dusty. The equipment also has to contend with these factors.

The instrument case and connectors need to be sealed from moisture and dust and the electronics able to withstand a wide range of temperatures. LCD screens, e.g., can fail if they are too hot and they are also affected by direct sunlight.

In addition, the field areas are often remote from power, repair facilities and sometimes the only means of transport is carrying by the operator.

2. Types of Surveys

Until the early 1990s, most geophysical surveying was for resources –oil & gas, coal, base metals and precious metals. This inevitably meant that the surveys were in locations remote from cities and towns with plenty of space and devoid of interference. One exception was archaeological and engineering surveys mostly taking place in Western Europe. Recently, environmental applications have become popular and engineering applications have increased. In general, these last two applications mean that the targets are much shallower than for resources (they are sometimes categorised as 'near-surface' geophysics) and often take place in or near cities and towns (hence the topic of "Urban Geophysics", see Henderson, 1992). This results in an increase in interference from anthropogenic (man-made, or 'culture') infrastructure and traffic and often involves confined spaces. It thus engenders a whole different way of operating and with smaller arrays and sometimes specially made equipment. Being nearer to 'civilisation' also means working in a less harsh environment − with human comforts close by. One aspect of

environmental and engineering (E&E) applications that needs to be handled specially is the fact that the situations are sometimes hazardous with in some cases, toxic chemicals involved. The particular branch dealing with the detection of unexploded bombs is particularly risky.

Archaeological applications are also 'near surface' as is the growing application to forensic investigations.

3. Choice of Method

The type of requirement will primarily determine which method, or methods, is optimum. Some methods are better suited to certain requirements than others.

E.g., Seismic Reflection is by far the most used method on petroleum targets because of its superior penetration and resolution capabilities.

It is important to use the methods that respond to the particular physical contrasts involved. E.g., massive sulphide deposits do not respond as well to I.P. as they do to EM. On the other hand, I.P. is more responsive than EM on disseminated sulphide targets. A method will not be useful if there is no contrast in the particular property on which it operates. E.g., if there is no detectable density change in the area, gravity should not be used.

Each method has particular capabilities and advantages and some limitations and disadvantages. Factors such as resolving power, speed and cost are some of the considerations in choosing which method. One method may not give as much information as another but the sacrifice in detail may be deemed acceptable because it is a lot faster or simpler to use. EM is a much faster way to measure ground conductivity than the DC electrical methods because the latter requires contact to the ground whereas EM methods do not. On the other hand, DC resistivity is less affected by high frequency noise.
All non-contact methods have the advantage of faster coverage. Non-contact methods should be preferred in the presence of contaminated ground.

Certain methods are better for layered targets such as underground water and in this case some methods have been developed especially to detect water.

4. Instrumentation

Throughout these notes the term "equipment" refers to the entire system of instruments and their ancillary items such as battery packs and cables, and the term "instrument(s)" refers to the main measurement unit(s). Often with newer instruments the recording and display part of an instrument is a separate laptop computer. The following comments on features also apply to these ancillary units.

Because of the peculiar environmental conditions outlined in Section 1, geophysical field instruments generally should have the following attributes.

4.1. Ruggedness – the ability to withstand being transported, sometimes roughly. Generally the equipment is delivered from the factory in strong, well-padded containers

designed for transport by airfreight. Such a '<u>shipping container</u>' and its attendant packing material should be retained for use in transporting equipment to the field site, or if not, (perhaps it takes up too much space) the delicate instrument(s), at least, should be well packed to withstand shock and vibration. For example, the constant vibration of corrugated gravel roads can unwind screws and cause circuit boards to come loose. Some instruments in particular, such as <u>gravimeters,</u> are almost too delicate for field use and need special care to transport. Gravimeters should never been consigned to freight unless they are built to withstand it. Check the manufacturers advice in this case. Preferably, a passenger should nurse them.

4.2. Portability - to allow for the situations where the only access to a site is on foot, instruments are generally designed to be able to be carried in their 'field mode' (i.e., without the transport packaging) by one or two persons. In general, instruments are therefore made to be as light as possible and usually have a carrying harness or handles.

5. Ancillary Equipment

Apart from the actual measurement instrument, there are generally other equipment items necessary to operate the instrument in the field. These include:
- sensors, if separate units,
- battery power source(s),
- generators, for higher power requirements,
- electrodes (for electrical contact with the ground),
- connecting cables and reels used to store and deploy the cables,
- connectors, if not attached to the cables,
- spare items of any or all of the above.

5.1. Sensors

The actual sensor may have to be separate from the measurement instrument to avoid being affected by the electronics or the metal in the instrument, or in the case of seismic geophones and electrical electrodes there may be multiple such units and they may need to be long distances away. Sensors should be treated carefully to avoid damage. Generally they will be in rugged housings and may have carrying handles.

5.2. Battery Power

For use in remote areas, field instruments have to have battery power. This can be in-built within the instrument or in separate units or '<u>battery boxes</u>'. Almost always the batteries are of the rechargeable kind and so come with a <u>recharger</u>. The later is usually left at the 'camp' or motel/hotel and connected to the field instrument overnight. If the battery power is not sufficient to power the instrument for a full days use, a second battery pack should be obtained. The battery pack that is not in use should be put on charge in readiness for its use. If the batteries are not rechargeable, as in many smaller units not requiring high power such as magnetometers and hand-held instruments, an adequate quantity of replacements should be procured if they are not readily available close by.

5.3. Cables

Cables provide the electrical connections between the instrument and its sensors or electrodes. They may consist of single or multiple conductors usually covered by plastic insulation. Long lengths should be kept on cable reels to avoid tangles and damage. They should not be walked on or worse, driven over. A break in the conductor can be very hard to find if the cable is not completely broken. Cables should not be left out over night if livestock are around as they chew them apparently to get the salt in the PVC insulation. Eating of PVC can harm the animals.

WARNING! Cables carrying electrical currents can be LETHAL. DO NOT TOUCH THE BARE WIRES. Even small amounts of current can kill by setting the heart into fibrillation. If you must pick up a bare wire, first test if it is live by using an insulated probe. If there is no other alternative but to use your hands, lightly touch with the BACK of the hand. If you feel a tingle it must not be touched again until the current is shut off. If a cable is live, touching by the front of the hand will cause the muscles in the hand to contract and actually grab the cable even more.

5.4. Cable Reels

Do not unwind cable off a reel (or "drum") too fast as it can 'free-run' and spool off too much. When winding cable back onto the reel, make sure it 'layers' evenly, do not let it pile up on one side as this can fall on to later windings and be very hard to unwind next time. Some reels have gears for different rates of reeling and may also have 'slip-rings' so that connection to the cable is maintained in any position of the cable.

If cable reels are not provided with the cables, 'hose-reels' from a hardware store can be used.

5.5. Connectors

Any special connectors provided, should be robust and able to keep moisture and dust out of the instruments. For multi-conductors especially, the connectors are often tough metal (although non-magnetic), so-called, 'military' type. Usually they have a 'keyway' that ensures that they are connected in the right way and are locked in place by turning on a thread. Generally they should be clamped to the cable to take any strain off the actual connections. To avoid any breaks of connection the connectors should not be disconnected by pulling on the cables.

As with cables, connectors should not be walked on or driven over. For some electrical methods, 'bullet connectors' are used, as they do not provide any obstruction when dragged along the ground. Non-special connectors such as 'crocodile clips' can be used in some cases so long as they are insulated from ground contact. Twisting bare wires together to make a connection should only be done in desperation.

6. Preparation Before Departing to the Field

To avoid problems in the field where high costs can be involved, it is vital to make careful preparations before departure. All the equipment should be checked for correct operation and that all necessary items are present and in working order. A 'check list' will facilitate this and if not available, one should be made up and used in future. Some instrument manuals have their own particular check-lists. Many instruments can be operated in the lab, some even have internal checking facility and these should be used. Gravimeters should be run over a nearby calibration range as a way of confirming their correct function at the same time as obtaining the necessary calibration factor. Defects that were noted from previous operation should be rectified if this has not already been done.

Depending on the type of field site and activity planned, other more general preparations for the operations should be made. See Milsom (2003) Sect. 1.2.5 for a very comprehensive tool-kit list. As a minimum, a universal screwdriver, wire cutters and insulating tape are most often needed. A first-aid kit should be carried

It is advisable to only take photocopies of Manuals to the field and keep the originals safe from loss and in good condition for subsequent copying. If the original manuals are taken to the field they should be protected from rain and dirt and preferably kept in the field camp.

When every item is ready, pack up the equipment so as to withstand the transport (see sect 4.1) and check it off against a list.

7. At The Field Site

7.1. Conduct of Crew in the Field

By following some simple guidelines and using commonsense, the conduct of the crew should not be cause for concern. One important rule is to LEAVE THE PLACE AS YOU FOUND IT where possible. If lines have to be cut through bush and/or holes dug for electrodes then such things must be done with as little disturbance as possible. If the area is private property, the owner should be advised and permission sought. All materials and rubbish should be removed from the site.

7.2. Unpacking Equipment

If a 'shipping container' has been used to transport the equipment, retain all the packing material for later use.

Check that all the required items are present against a 'check list'. Such a list may be provided in the manual for the instruments.

7.3. General Precautions

7.3.1. The Manual

Wasted time and trouble can be avoided by carefully reading the Manual for the instrument and carrying out all the instructions in the right order. Generally the advice

offered is a result of experience and feedback from previous wrongful use and should be heeded. In particular, take note of any warnings usually at the front of the manual.

7.3.2.   Instrument Specifications

The specification should be studied, in particular to note such factors that may affect the operation of the instrument, especially in the existing circumstances. The specifications are typically included in the Manual often as an Appendix. For example, the temperature range of the instrument may not be high enough for the prevailing conditions in which case special effort has to be made to keep it cool. The specifications will also indicate how waterproof is the instrument and whether it can still operate in light rain or not.

7.4. Specific Operational Precautions.

Some precautions are specific to the method. The ability of the particular instrument to detect unwanted responses is to some extent dependent on its level of sensitivity (See Sect 9.1) and needs to be judged individually.

For example, with the magnetic method, care should be taken not to have any magnetisable metal close to the sensor. Metal items of clothing such as belt buckles and even clasps in baseball caps can be detected with the more sensitive new instruments and should be removed if suspected of causing effects. 'Cultural' objects such as sheds, fences, etc should be avoided. Vehicles should be moved out of effect.

In the case of gravity surveying, only very large masses such as nearby terrain can produce additional responses but vibration such as from wind or traffic should be avoided. In windy conditions, the meter should be shielded in some way to defect the wind. When surveying with gravimeters in cities, readings are often made at night when the traffic has ceased or is minimal.

For ground radar, objects on the surface near the antennae can produce reflections that can be confused with targets in the subsurface.

With electrical methods, the main precaution is to avoid electrocution of personnel. The latter can include field crew and in some situations, the public. As stated above (Sect. 5.3) no one should touch unshielded live wires. Before turning on current ensure that all conductors that are about to become live including grounded electrodes, are clear from personnel. Electrode arrays should not be set up near long wire fences, especially sub-parallel to them. This also applies to parallel sets of cables especially if one line is carrying current and the other is measuring voltage. In this case unwanted voltage can be induced into the voltage line by the process of 'coupling'. Surface water will produce anomalous electrical readings.

For the electromagnetic method, any surface object that can be 'electro magnetised' (or 'induced') should be avoided. A common such source are coils of cable near the receivers. In the case of Frequency- Domain EM (as distinct from Time-domain EM) the exact spacings between separate transmitter and receiver are critical as they can effect the measurement by large percentages.

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For seismic surveys, if explosives are used as a source fully trained and licensed operators should manage them. In fact explosives should be avoided in favour of alternative sources where possible. (See Milsom Sects. 11.2.3 and 11.2.4 for more on this).

8. Selection of Survey Parameters

Readings should preferably be acquired on a regular grid although this is not always necessary or expedient. Before deciding on the optimum parameters such as line spacing and direction, reading spacing, etc., it may be appropriate in the first instance to conduct a 'reconnaissance' of the area to be surveyed with a limited number of readings. This 'trial' survey can allow a decision to be made, firstly as to whether it will be worthwhile at all to conduct a more 'detailed' survey and then, what parameters are best. If possible and the situation at the site allows it, a regular grid with coordinates specified as north and east of some arbitrary or special origin, is best. This allows each measurement position or 'station' to be labelled unambiguously, e.g., as 100N200E. Later readings that may be required to provide more detail of particular areas, called 'in-fill' readings, can then be labelled in this same scheme. E.g., if a reading is inserted later half way between 100E and 200E it becomes 150E. A well-defined grid can, if needed, be incorporated into a wider coordinate system and allow for the matching and overlaying of the data with other information.

Labelling survey lines in some other way such as "Line A" and "Line B" adjacent to it does not permit a logical way to label an intermediate in-fill line.

If satellite navigation instruments such as "GPS" receivers are used to define positions the global coordinates they read can be used. The use of such receivers is particularly expedient for reconnaissance surveying or when not using a grid.
In the case of multiple electrode or geophone arrays, the coordinates of the individual positions can be noted, particularly if the spacings are large, or just the centre position noted together with the spacing of the electrodes. For large EM loops, the corners can be assigned their appropriate coordinate values.

Station positions should be clearly marked with stakes and labelled so that they can be easily and exactly recovered if repeat readings are necessary, or if they have to be re-occupied by another method. Also, positions may need to be recovered for subsequent investigations and/or siting of drill holes.

8.1. Traverse or Line Spacing

A compromise has to be reached with the ideal of a 'saturation' of lines and the need for efficiency (See Sect.12). The line spacing should however, be such as to have at least 3 lines crossing the anomaly (as distinct from the target which may have a smaller spatial extent) and for further expediency, it is best that they are parallel and across the widest part of the anomaly. Probability theory gives the spacing required to have at least one crossing of a given shape. In the ideal case of a sphere, e.g., the spacing must equal or be less than the diameter of the sphere. There are other spacing requirements for other shapes.

8.2. Station Spacing

A similar compromise exists between reading too close together which take up time and may not always exhibit new information and the need to get optimum coverage of the anomaly. In this case there should be sufficient readings on the anomaly to resolve its full shape. If the spacing is too great the shape will be too smooth. This is a case of insufficient sampling of data and the result is termed 'aliasing' of data.

8.3 Orientation of Lines

For maximum efficiency, lines should be oriented so as to gain the greatest amount of change over the anomaly. If the anomaly is very elongated, lines perpendicular to the axis of elongation are optimum. Lines parallel to the axis of elongation are in the worst direction as they will read essentially the same values along their length. It may not always be possible to achieve the optimum due to topographic or anthropomorphic obstacles, but as great an angle to the elongation should be aimed for. The angle is certainly something to note in a 'Comments' section. (See Sect 10).

9. Field Readings

9.1. Sensitivity, Precision and Accuracy

Instrument specifications may quote values for one of more of these parameters. It is important to understand the differences.

The *sensitivity* of an instrument is its ability to detect changes in measurement values. Sensitivity is high and therefore most desired when a small change can be detected. It is quoted as the amount of change per some other index, e.g., for a voltmeter it might be so many ohms per volt. Some modern instruments are very sensitive when considered in relation to the normal field values they measure. E.g., gravimeters are sensitive to 1 part in 10^{-9} of the Earth's average gravity value. The value of the very smallest change detectable is the 'resolution' of the instrument.

The *precision* of an instrument is a measure of its ability to give close *repeatability* of a number of readings. This assumes the reading input is not changing for some reason such as 'drift' due to temperature, or whatever. The term, precision also comes into recording the mean of a set of readings. There is no point in recording a mean value to many decimal places if the instrument is not capable of reading to that level in any one measurement.

Accuracy is the closeness of a reading to its true value. The amount of difference is the 'error'. (See Sect. 9.2). The aim should always be to get the best accuracy possible. As shown in Appendix 1, accuracy can be improved in some circumstances in the presence of variable readings by repeated measurements.

9.2. Errors

The result of any measurement can never be absolutely correct for a number of, mainly practical, reasons and hence there is always some error. The 'reliability' to be placed on a measurement can be expressed in terms of this error. Expression of the error allows for a judgement to be made as to the confidence that can be placed in the value(s).

Errors can also arise from inaccuracies in position on a grid and if arrays are used, errors in their spacings and shape. A certain amount of inaccuracy can be tolerated as an acceptable percentage error. E.g., if electrodes are to be 10.0 m apart, this assumption will be correct to an acceptable error of 2% or less, if they are actually somewhere between 9.8 and 10.2 m apart. Where the theory of a method assumes a "point source" for an electrode the practical electrode size must not be too large in relation to the spacing so as not to contradict this assumption.

In a field situation, the theoretical requirement cannot always be met and a compromise position or shape may have to be used. In this case, the error, or an estimate of the likely error, should be made and noted in the "Comments" (Sect 10).

9.2.1. Types of Error

There can be many types of error – 'accountable errors' and 'unaccountable errors' are some. An example of an accountable error is a systematic error such as the instrument being out of adjustment or wrongly calibrated. There may be many reasons for this. It can be corrected by readjustment or calibration when the constant error is included in the reading. Such error can be detected by regular calibration. Another type of accountable error is observer error – reading incorrectly. A common error of this type is parallax – reading a dial at an oblique angle. Observer, or personal, errors can be detected when another observer makes the same readings and a systematic difference is observed between them.

Unaccountable errors are just what the name implies. They are random and may show up as a nonsensical variation. The reason for them may be unknown. They can be detected by 'order-of-magnitude' checks of what is expected or by some independent measurement. Their occurrence may be lessened by better quality procedures.

The Radiometric method, because it measures random signals from the effects of cosmic radiation, requires multiple readings to be taken at each station, as the final value at any place is necessarily a statistical average. For the reasons given in Appendix 1.this value will 'narrow' in its spread of measurements with the more readings taken.

In general, results can be improved and 'anomalies' (See Sect 15) better defined by acquiring more readings in a given distance or space. This can be achieved with fast reading instruments and solid-state storage and is sometimes done to excess knowing that the optimum result can be extracted from all the data by software. In this procedure of deliberate 'data redundancy', care should be taken to ensure that the readings are at least in the right order of magnitude before accepting them.

9.2.2. Various Expressions of Error

One reason for the inability to read correctly can be the limit of reading of the particular instrument involved. The reading error of an instrument might be quoted as some percentage of its full range, e.g., 3% of full scale.

If an instrument only reads to one decimal point and repeat readings give the same figure, the maximum error is half of this last significant figure. E.g., if the reading is 72.8, then the maximum error is 0.05. (If the error is more than 0.05, then the reading would have

been 72.7 or 72.9). For the <u>relative magnitude</u> of the error, it can then be expressed as a percentage of the value (5/72.8% or 0.069%), called the <u>'percentage error'.</u> The error of 0.05 would be much more of a concern if it related to a reading of say, 7.8, as in this case the relative error is 0.64%.

See Appendix 1 for more on the statistical expressions of error.

10. <u>Comments with Readings</u>

When acquiring or recording readings it is best practice to include a "Comments" column wherein pertinent remarks can be made. These can be very useful later in resolving confusion and in analysing and interpreting results. Possible errors in the field set-up, as described in Section 9.2, are one type of comment. In this case, the reason for any necessary compromise should be noted. Comments are especially important in surveys in 'built-up' areas where the amount and type of interference is generally much greater. Suspected interference such as from surface objects or terrain should be noted, as they will help to explain odd or uncharacteristic readings; "Fence line 5 m from station", "conductive water near electrode", "buried pipe near magnetometer sensor", etc. Notes about the ambient conditions can also be helpful; "strong gust of wind at time of reading", and remarks about the topography will be especially useful for gravity corrections. Notes on the type of outcrop present will help with identifying the location if they can be matched to mapped geology. Also this information can help with the interpretation possibilities.

If laptops or electronic storage devices are used to record readings, provision for comments should also be included in them. Some instruments with solid-state memory have the ability to note comments.

A diagram or simple <u>plan of the grid layout</u> annotated with its relation to permanent objects such as sheds, gates, cables, etc. is a good back-up to the comments and can help to recover positions should it be necessary to repeat a reading later or continue measurements from a previous station.

11. <u>Base Stations</u>

Some methods use fields that vary in time. These include the magnetic and gravity fields and natural EM fields. E.g., the magnetic field has a daily variation called the <u>'diurnal'</u> change, the gravity field varies due to tidal effects of the moon and EM fields vary due to solar phenomenon. To correct for these variations, the field is either monitored separately or readings are repeated at specific time intervals.

If the base is to be used at some later date, say, for the extension of the survey area, then it is important that the position be marked well and permanently. A description of the position should be recorded so as to locate it unambiguously. (E.g.,"2.3 m SSE of the fence post and 8 m NE of the water pump"). This is best done with an accompanying sketch map. (See Milsom Fig.2.7 for examples). Use points of reference that are relatively permanent.
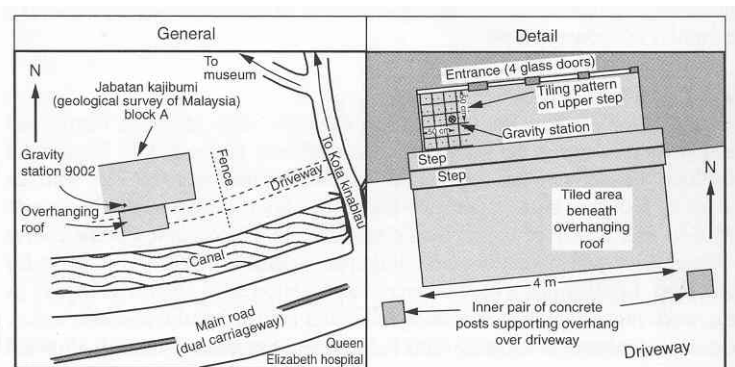
Figure 2.7 *Gravity base-station sketches. Two sketches, at different scales, together with a short written description, are usually needed to ensure the station can be reoccupied quickly and accurately.*

When a base is reused from a previous survey or if it is a regional base to which the survey should be connected, this is called 'tieing' the survey to this base.

11.1 Continuous Recording

The best way to detect and monitor temporal variations is to have a second instrument placed at some fixed position with continuous recording capability. This is particularly necessary in the case of magnetic surveying when rapid changes in the field due to solar activity cause magnetic 'storms'. This type of recording is then often called a 'storm monitor'. During strong and rapid magnetic variations, the survey may have to be temporarily halted. A danger with a recording monitor when it is left unattended is that it may malfunction causing correction information to be lost. To avoid this as much as possible it should be checked periodically. Especially, the recorder should have adequate power for the time it is required to be on.
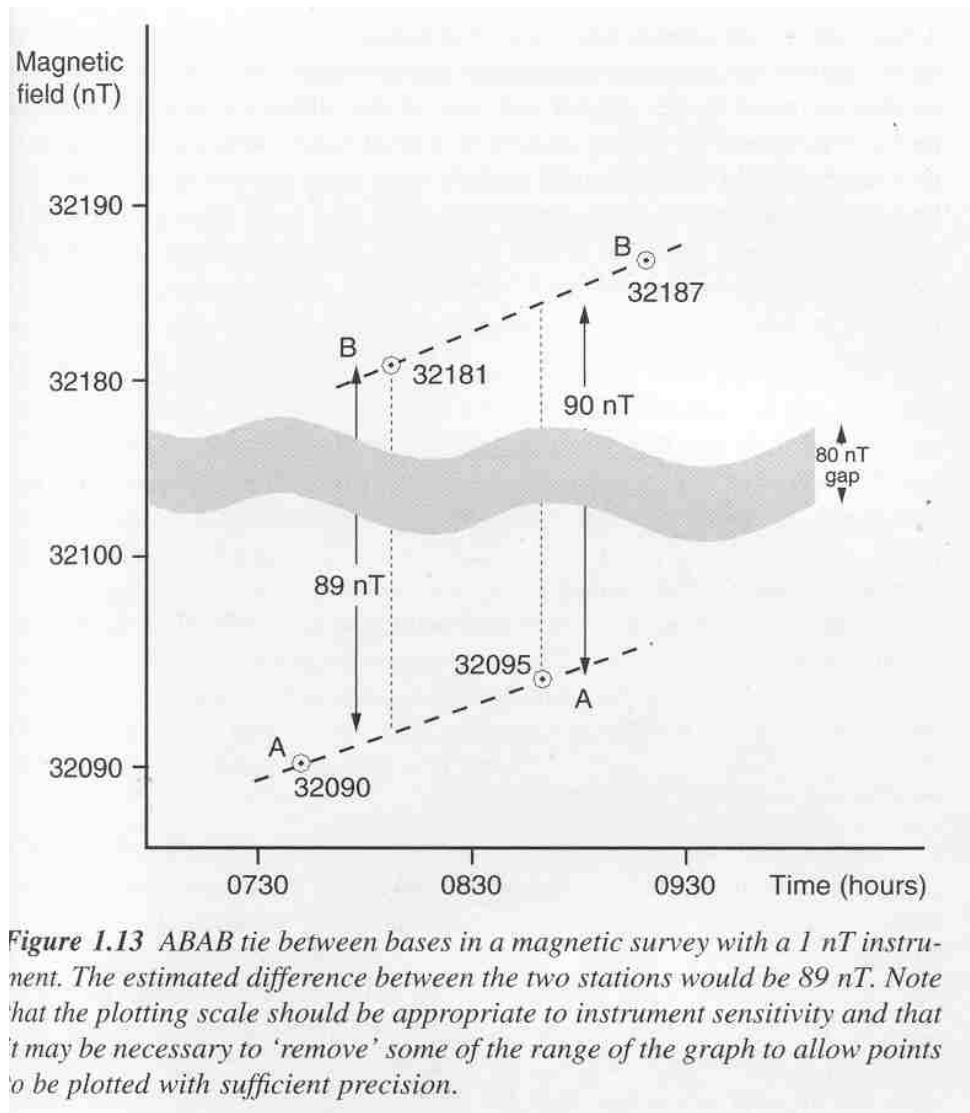
11.2 Periodic Repeat Reading

If a second instrument is not available to be used as a monitor then field changes can be measured with the one survey instrument by taking repeat readings at a fixed position over time. This can also be done to determine the amount of 'drift' in an instrument and to correct for it. If the readings and the time at which they are measured are recorded the change can be evaluated. This variation can then be applied to roving field stations at the corresponding times that those measurements were made and an adjustment made for it. This is commonly called applying 'drift corrections' even though it is not related to instrument drift, necessarily.

It is important that the position of base stations be chosen carefully so that they are themselves not the cause of some changes. E.g., siting a gravity base near a tree may experience some unpredictable vibrations in the ground. In built-up areas movement of parked vehicles will affect magnetic base readings. Choose places that are easy to get to so as to save time when returning. Don't, e.g., choose a place in a car park that may be occupied by a car on your return.

The frequency of time with which repeat readings are made at a base is determined by the rapidity of the field change. A fast changing field requires frequent repeats.
To save time in returning to an increasingly distant base when the roving readings become further away, a new base can be established closer to the survey. There is a certain

procedure to determine the difference in values between the old and the new bases that takes account of the time variation. (See Milsom Fig. 1.13).

Figure 1.13 *ABAB tie between bases in a magnetic survey with a 1 nT instrument. The estimated difference between the two stations would be 89 nT. Note that the plotting scale should be appropriate to instrument sensitivity and that it may be necessary to 'remove' some of the range of the graph to allow points to be plotted with sufficient precision.*

In this procedure, it is important to be satisfied that the repeat readings are close enough in time for the variation to be at least approximately linear over the time difference and also that the difference between two stations for at least two sets of readings are within a reasonable margin of error. The re-establishment of the base may be necessary a number of times. A series of such bases may form what is called a 'network'. Where a network includes a closed loop, the individual differences that make up the loop can be added to produce a total difference, or 'misclosure'. If the value of the misclosure is outside acceptable error limits individual readings should be checked for error and if necessary, corrected by re-reading them. Networks are thus a good way to ensure correctness of measurements. (See Milsom Fig.1.14). See Sect 15.
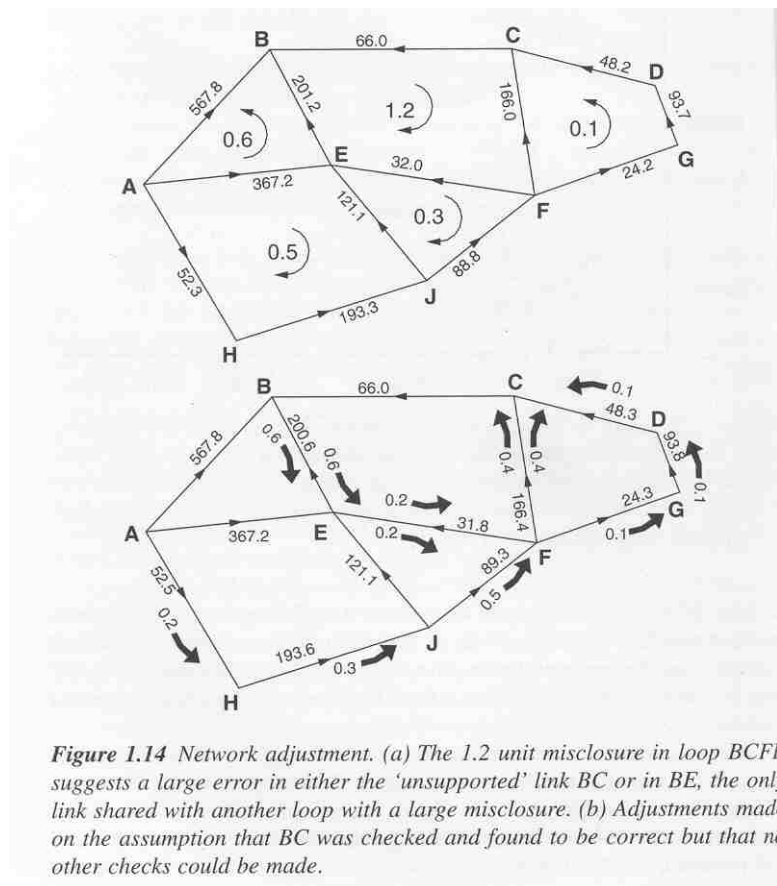
Figure 1.14 Network adjustment. (a) The 1.2 unit misclosure in loop BCFE suggests a large error in either the 'unsupported' link BC or in BE, the only link shared with another loop with a large misclosure. (b) Adjustments made on the assumption that BC was checked and found to be correct but that no other checks could be made.

11.3. Gradiometers

The use of gradiometers, where two or more sensors are read at the same time, avoids the need for base monitoring. Since a gradiometer involves the measurement of a field over short spacings simultaneously, any temporal change is the same at these places and when a gradient is obtained by calculating the difference in two readings, it's effect is cancelled out. It is one of the advantages of using gradiometers that they obviate the need for base repeats. (It is especially advantageous for airborne surveying). Gradiometers also remove any common values which may be unwanted 'regional" effects. (See Sect. 14).

12. Efficiency

"Time is money" is a truism in field surveying. Extra costs apply when a crew is in the field and may include travel, the rental of equipment and vehicles and special accommodation. To avoid unnecessary expense the survey should be carried out as efficiently as possible. In particular, time should be saved whenever it can be and mistakes that require repeating readings avoided if possible. These attributes have been alluded to above. The extra time to get a more accurate reading has to be judged as necessary in relation to the extra cost it will incur. Established ways to layout field arrays that are more efficient of time and personnel usage should be used or new ones specially devised.

13. <u>Signal and Noise</u>

Field operations are concerned very much with these two factors and it is important to understand their significances and differences.

13.1. Definitions and Examples

Signal is the reading that is measured by the instruments. It can be in two main parts – the 'anomaly' (see below for more on 'anomaly') that is wanted and an <u>unwanted</u> part added to it that is described by the all-encompassing term, ***noise***. Noise is often characterised by being not <u>'coherent'</u>, i.e., it varies with time and /or position. Very incoherent noise can sometimes be referred to as 'dirty' noise. The electrical ignition field of a portable power source used with transmitters can provide this type of noise. Some other examples of variable noise are natural atmospheric electromagnetic signals and vibrations due to wind or traffic.

Noise can also be a consistent <u>'background'</u> response that is not providing information on the objective of the search. Consistent noise might be a power line field or the magnetic response from a nearby pipeline or cable.

In many of these cases the interfering noise can, for other methods, be the wanted signal or the source field for the measurements. E.g., the atmospherics that might disturb an electrical or EM survey can be the source field for another type of EM method (Magnetotellurics). Recently more ways are being found to make use of what was once considered noise, to provide the source signal, or possibly, additional information about the target. E. g., the traffic noise mentioned above is now used as a source for a special type of (shallow) seismic surveying. The variability of readings in a survey may in themselves be indicative of the type of geology especially in the regolith. This double role of noise has lead to the often-quoted saying; "that one persons noise is another persons signal".

These concepts of signal and noise can be considered by forming the ratio, <u>signal/noise</u>, often abbreviated as 'S/N'. If, as is desired, this ratio has a high value, it can indicate that signal is high, or noise is low, or both.

Because the presence of noise can be so common it is recognised that in theoretical modelling of synthetic targets, some noise has to be artificially added to make the results more realistic. Often for what of a better idea, random Gaussian noise of some small percentage of the total signal is added.

13.2. Cancellation or Reduction of Noise

Various measures have been developed to cancel or reduce the effect of noise in readings. Continuous incoherent noise can be cancelled or substantially reduced by adding together a large number of repeated readings. Statistics shows that the variable part of the reading, the noise, will cancel or reduce. The more readings the better the result. Of course this all takes more time than would taking one reading and there is a trade-off in terms of the delay it may cause. Often a compromise has to be reached between the time taken to complete the readings and the closeness or accuracy of the result. This technique of adding a number of readings is called "<u>stacking</u>". Constant noise can be cancelled or '<u>muted</u>' as it is called in the case of seismic signals. In EM, the constant signal from the transmitter

which may otherwise overwhelm or 'swamp' the much smaller signal from the target can be reduced in strength or 'bucked' out by opposing it with other transmitter coils. Some instruments have 'filters' for rejecting predictable noise. A common filter for EM methods is the power line frequency. This works so long as the frequency is constant within a defined envelope. In less well-developed countries this variation can be too great for the filter to cope. Also at some mine sites the frequency is a totally different value to the norm, say 40 Hz instead of the usual 50 Hz.

14. Determining The Anomaly

The purpose of geophysical surveying can be simply stated as the search for an anomaly or anomalies. Anomalies are variations or changes from 'normal' values, generally in spatial terms but in the case of monitoring, say of pollution, it can be changes with time. (It is assumed that the measured values have any noise removed as described in Sect.14.2). Normal values are also referred to as 'background' and the difference from background is the quantitative measure of the anomaly. To determine the value or spatial extent of an anomaly requires the background to be defined. (Some surveys may be carried out purely to define background for later use). Some spatial background variations are known theoretically such as the normal gravity and magnetic fields (the latter being described by the "IGRF"). Both fields have standard variations with position on the Earth and readings can be corrected for them. Even after the removal of these standard variations there may still be a background field, generally distinguished by being smoothly varying, over a wider area than the search area and due perhaps, to deeper geological formations than the zone of interest. This is called the 'regional' and when it is removed from the readings to obtain the anomaly what remains is referred to as the 'residual'. Some regionals can be removed in software using mathematical 'filters'. Gradiometers also remove deeper-seated responses and so act as a filter to regional variations.

It is important to ensure that sufficient readings are taken to adequately define an anomaly. One reading only at one time or station is never sufficient. Generally, anomalous change is a smooth effect over some distance or time and reaching a maximum value and then decreasing. Enough readings should be taken to adequately map this variation. Correct interpretation relies on adequate definition of an anomaly.

The value of any residual anomaly can be the result of several individual responses added together. Some responses are due to geometric factors (such as distance from the source, the size of the measurement arrays, etc.) and some to the relevant physical property contrasts

15. Before Departure

It is imperative before ending a survey that all the readings be checked for completeness and correctness. This will avoid the possibility of having to return to the area to correct any errors. If nothing else, this is costly as stated in sect. 6.6. Checks should be made on the integrity of the results such as checking misclosures (Sect 6.5) Preferably duplicate 'back-ups' of the data should be made and kept separately from the originals before closing down the survey.

References

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Key words

The words above that are underlined and in quotation commas, are words whose meanings should all be understood. There will be an exercise that will ask for an explanation of some of them chosen at random.
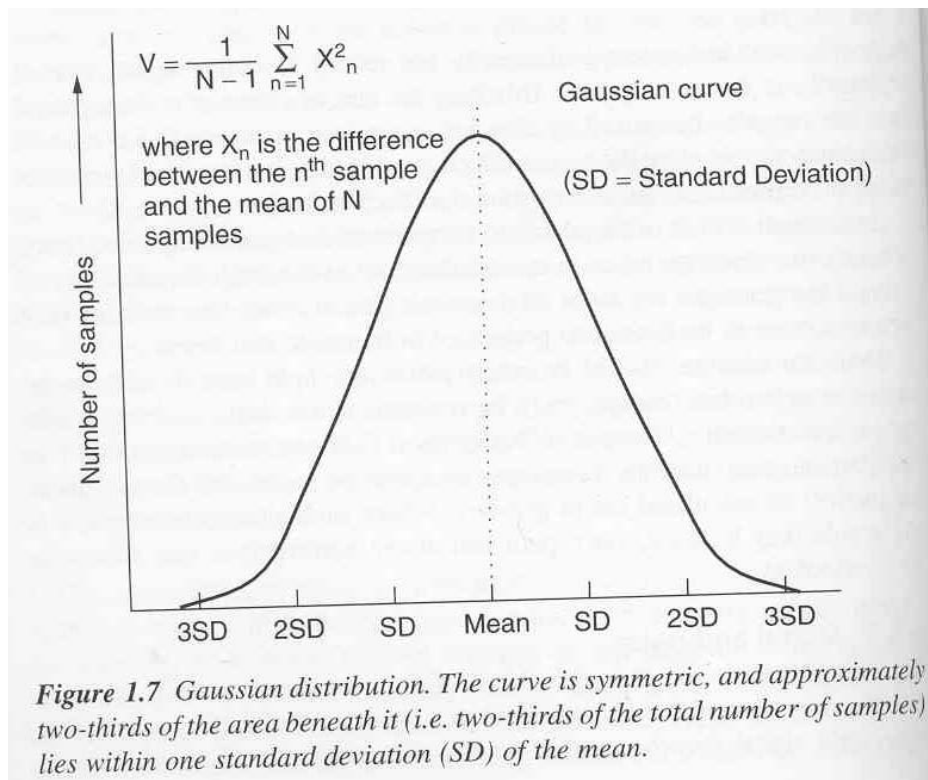
Appendix 1

Some Statistical Expressions of Error

When a measurement is some combination of a number of separate observations by addition and/or subtraction, the maximum error of the final measurement is the *sum of the individual errors.* When the measurement is the result of multiplications and/or divisions, the percentage error is used as the *sum of the individual percentage errors.*
Statistical theory suggests however, that the more likely error in each case is the *square root of the sum of the squares of the errors*. For this purpose, a higher power is treated as successive multiplication.

When repeat readings are not the same, especially due to the presence of random errors, statistical methods give other expressions of the error. For a large number of readings, the probable error is not as great as the maximum error and is reduced by the greater the number of readings (n) taken. For this reason, the expressions usually incorporate 'n' as a divisor.

When random variations (i.e., no systematic errors present) assume a 'Gaussian' distribution (a symmetrical distribution about a mean value), see Milson Fig 1.7, one statistical measure of error is the **variance (V)**, the *sum of the squares of all the differences from the mean value divided by 'n'*. Another measure is the **standard deviation (SD)**, the *square root of 'V'*, also called the root –mean-square (RMS) error. Two thirds of 'n' are less than one SD. As half of all 'n' fall within +/- 0.6745SD, this is sometimes called the 'probable error'. Yet another measure is the standard deviation divided by the square root of the number of readings (SD/√n), called the "standard error of the mean".

$$V = \frac{1}{N-1} \sum_{n=1}^{N} X^2_n$$

where X_n is the difference between the nth sample and the mean of N samples

Gaussian curve

(SD = Standard Deviation)

Number of samples

3SD 2SD SD Mean SD 2SD 3SD

Figure 1.7 Gaussian distribution. The curve is symmetric, and approximately two-thirds of the area beneath it (i.e. two-thirds of the total number of samples) lies within one standard deviation (SD) of the mean.

Both measures are improved by a larger number of readings (n). However, the time to take a number of repeat readings in an attempt to improve the accuracy has to be weighed up against the imperative to achieve good progress. Usually only one repeat reading is sufficient providing it does not differ from the first by an amount within the expected range of error. With fast reading instruments, more readings can be taken without too much time penalty and if automatic recording is available, such as electronic storage, this can be not a big impost.