Glossary of Useful Terms

A list of useful geophysical terminology compiled from the UBC-GIF Glossary of Inversion Terms (http://www.eos.ubc.ca/research/ubcgif/), the Geo-Services International Applied Geophysics Methods (http://www.geophysics.co.uk/methods.html), the Schlumberger Oilfield Glossary (http://www.glossary.oilfield.slb.com/) and the Encyclopedic Dictionary of Applied Geophysics (4th Edition, by Robert E. Sheriff).

***A Priori* Information**
A priori information is often used to refer to knowledge about the Earth model that is not classified as data in terms of an inversion. Additional information of the Earth such as a known background or reference model, an expected structure or geometry, and known specific physical properties that can be assigned to cells and used to constrain and guide the inversion.

Anomaly
Anomaly is a term that is used in two ways and therefore is occasionally confusing. In general, the word means anything that is "not normal". In the context of data, we usually hope that the target or feature of interest will produce a measurable anomaly (variation in the dataset) which can then be interpreted in terms of what caused it. In the context of the Earth's subsurface (or the geophysical model), a feature that can be detected or characterized may be referred to as an anomaly or an anomalous zone. For example, a subsurface void is a "density anomaly" that should produce a measurable "gravity anomaly" if a gravity survey is carried out over the void.

Bounds
In an integrated approach to exploration, geophysical survey data is complemented by direct sampling and other geological information. As a consequence, inversions of geophysical survey data can be constrained by setting upper and lower bounds (upper and lower cutoffs) on the model values. The UBC GIF codes allow for setting global bounds, which are applied to the entire model, or the user can specify bounds on a cell by cell basis within a “bounds” input file (for MAG3D the bounds file is called “bounds.sus”).

Channel
A time gate during which measurements are made in time-domain EM, frequency-domain EM, or IP surveying. Measurements made during several time gates following a source pulse yield several channels of data.

Chargeability
Time domain IP surveys involve measurement of the magnitude of the polarization voltage (Vp) that results from the injection of pulsed electric current into the ground. Polarization voltages primarily result from electrochemical action (ionic exchange) within the pores and pore fluids of the material being energised. The current is applied in the form of a square waveform, with the polarisation voltage being measured over a series of time intervals after each current cut-off using non-polarising electrodes. The measured value of Vp is divided by the steady voltage (observed whilst the current is on) to give the apparent chargeability of the ground. This provides qualitative information on the subsurface geology. TD-IP is primarily used in mineral exploration surveys.

Chi-Factor
The Chi-factor is the ratio of data-misfit to the number of data and controls the degree to which the data are fit during an inversion. A Chi-factor of less than one would over-fit the data while a Chi-factor of greater than one would under-fit the data.

Common Earth Model
An explicit, quantitative model of the Earth consistent with all data, testable by drilling, and subject to editing and refinement as the collection of new data proceeds.

Conductivity
The ability of a material to conduct electrical current. In an isotropic material, the reciprocal of resistivity. Units: Siemens per meter.

Constrained Modelling
Modelling using geologic or physical property information (e.g. drill-holes, geologic maps, outcrop physical property samples) as a constraint on the inversion process. Produces more reliable models that are consistent with multiple datasets.

Data
Data are measurements of a physical phenomenon such as a field, flux, current, or force, etc. They should be accompanied by an estimated uncertainty. To understand and work with data in inversion, it is imperative that details of the survey and instrumentation are known, viz locations/orientations of transmitters and receivers, transmitter strength, receiver gains and any processing that has been done to the data.

Data Misfit
Any useful model of the Earth recovered by inversion must be capable of causing the dataset that was observed. This is tested by comparing field measurements to a synthetic dataset generated by forward modelling based upon this recovered model. We say the model "fits the data" if it is capable of generating data that match the field measurements to within a specified degree. Data misfit describes how close predicted data are to the field measurements. Often we plot the real and synthetic datasets to compare for similarity. Sometimes a plot of the difference between the two datasets is generated to emphasize that variations between the two are small. Data misfit is commonly quantified with RMS or L_2 difference norms.

DC Resistivity Method
Observation of electric fields caused by current introduced into the ground as a means for studying earth resistivity. The term normally includes only those methods in which a very low frequency or direct current is used to measure the apparent resistivity.

DCIP3D
The DCIP3D is a program library that performs forward modelling and inversion of DC resistivity and IP data over a 3D distribution of electrical conductivity and chargeability. The programs in the library work with data that are acquired using general electrode configurations and at arbitrary observation locations either on the Earth's surface or in a borehole. 3D surface topography is also fully incorporated in the modelling and inversion. *(See 3-D inversion of induced polarization data, Li Y., and Oldenburg D.W. (2000), Geophysics, 65, #6, pp 1931-1945.)*

Density Contrast
If different rock types have different mass densities, then there will be spatial variation of mass density between (and sometimes within) rock units. This variation, known as the density contrast, affects both the local gravitational field (measured in gravity surveys) as well as the acoustic impedance contrast (and thus the reflection coefficients in seismic surveys).

Discretization
Although the Earth has a continuous distribution of physical properties, we simplify this with a discretization that describes the Earth as a model containing a number of cells each having a constant physical property. This model is defined on a 1D, 2D, or 3D grid or mesh. The size of the cells should reflect the resolving power of the survey. If the cells are too large important, geologic features may not be adequately modeled. If they are too small, it shouldn't adversely affect the inversion outcome but it may slow the process down due to an increase in the size of the system of equations to be solved.

Forward Modelling
In general, modelling usually refers to the process of developing models of the Earth based upon measured geophysical data. It may be as simple as recognizing that an anomaly is likely caused by a buried pipe, or it may involve sophisticated data processing and/or inversion to mathematically build a range of plausible models. Forward modelling means simulating the data that would occur if a survey were gathered over a known model of the Earth.

Free-Air Anomaly
Gravity data that have been corrected for latitude and elevation (free-air correction) but not for the density of the rock between the datum and the measurement elevation (Bouguer correction). Measures the attraction because of the mass of the subadjacent earth. Also called free-air gravity.

Frequency Domain
A representation in which frequency is the independent variable; the Fourier transform variable when transforming from time.

Frequency Domain Method
A method of potential-field analysis in which parameters of interest are estimated from characteristics of amplitude and phase spectra. Involves the variation of apparent resistivity with frequency.

Geophysical Model
A geophysical model is a simplified concept of how one physical property is distributed within the Earth. Geophysical models are generally an object, a halfspace, 1D (layered earth), 2D, or 3D. Note that a "model of the Earth" can mean either a geological model in which the subsurface is described in terms of rock types, structures, fluids, etc., or a geophysical model defined here in terms of physical properties and physical property contrasts.

Gocad Mining Suite
A mining-customized extension to the Gocad (Geological Object Computer Aided Design)
modelling engine. Features include highly sophisticated yet simple to understand geological modelling, powerfully interactive 3D editing, enormous power in structural modelling, surface (wireframe) construction, stratigraphic and regular block modelling, and geostatistics. Mining Suite modules include a range of mining-specific i/o filters and utilities, a 3D-GIS spatial analysis and query environment,

natural connections to geologically-constrained geophysical forward modelling and inversion, multi-disciplinary 3D expert-system exploration targeting, and geotechnical hazard estimation and monitoring.

GRAV3D
GRAV3D is a program developed by the UBC Geophysical Inversion Facility (UBC-GIF) for carrying out forward modelling and inversion of surface, airborne, and/or borehole gravity data in three dimensions. The program library carries out the following functions: 1) forward modelling of the vertical component of the gravity response to a 3D volume of density contrast, and 2) inversion of surface, and/or airborne gravity data to generate 3D models of density contrast.

Gravity Gradiometry
The study and measurement of variations in the acceleration due to gravity.

Halfspace
A volume in which half is "air" and the other half is a constant value. Geophysicists consider the Earth to be a "halfspace" when the whole volume that is visible has only a constant value of the relevant physical property.

Induced Polarization (IP)
This term is used both to refer to a phenomenon and to the type of field survey that measures this phenomenon. Electric charges in the ground, and the way in which they interact with surfaces of mineral grains, are affected by application of an electric field. The effects can be measured by recording dynamic time or frequency behaviour of potentials caused by the application of the field.

International Geomagnetic Reference Field (IGRF)
A long wavelength regional magnetic-field model determined by an international committee about every five years (e.g., 1965, 1975, 1980); expected secular changes are included. The model consists of spherical harmonics. The IGRF is subtracted from observed data to determine the local field.

Interpretation
Interpretation of geophysical data involves two steps. First the data must be interpreted in terms of a causative distribution of the relevant physical property. Then this "model" can be interpreted in terms of geology (structures, minerals, rock type alteration, etc). Geophysical interpretation may be carried out in many ways, ranging from simple data inspection to sophisticated inversion and modelling.

Inversion
Inversion (or inverse modelling) is the process of mathematically estimating one or more models of subsurface physical property distributions that could explain a dataset that was gathered in the field.

MAG3D
MAG3D is a program library developed by the UBC Geophysical Inversion Facility (UBC-GIF) for carrying out forward modelling and inversion of surface, airborne, and/or borehole magnetic data in the presence of a three dimensional Earth. The program library carries out the following functions: 1) forward modelling of the magnetic field anomaly response to a 3D volume of susceptibility contrast, and 2) inversion of surface, airborne, and/or borehole magnetic data to generate 3D models of susceptibility contrast.

Magnetic Susceptibility
A measure of the degree to which a substance may be magnetized. Rock susceptibility is often proportional to the fraction of magnetite present. Units: cgs or S.I.

Magnetization
Local magnetic anomalies in the data are due to the magnetic field produced by magnetically susceptible material beneath the surface that has been magnetized by the Earth's ambient magnetic field. The majority of the response comes from shallow material due to the fast fall-off nature of the magnetic field.

Mass Density
All known physical matter, including rocks, has mass. Mass density is the term given to the mass per unit volume (typically reported in units of g/cm^3) of a given material. In geophysics, the mass density of rock units is fundamentally important as it is linked to the gravitational field (E.g., higher mass density => stronger gravity) and the speed of sound in rock (E.g., higher mass density => faster sound speed).

Mesh
A 1D, 2D or 3D grid used to approximate a continuous or semi-continuous surface or volume for computer modelling. *See Discretization.*

Non-uniqueness
In mathematical context, "non-uniqueness," simply means that no single (unique) solution exists for a given mathematical problem. Such a problem has at least two equally valid solutions and could in fact have an infinite number of solutions. Geophysicists must wrestle with this concept of non-uniqueness every time they tackle a geophysical problem which in real-life is always an "under-determined" problem (i.e., we have more unknowns than data). Furthermore, real data are always noisy (i.e., we have a range of possible values for each datum that are all possible within the error range) and data may not contain sufficient information as is the case with magnetic and gravity data which contain no depth information. In such situations, we can have an infinite number of mathematically valid Earth models that explain the same geophysical data. Just because a solution is "mathematically valid" does not mean that is physically or geologically reasonable. Geophysicists use this concept of what is geologically reasonable along with other a priori information (i.e., geologic sections, core samples, etc.) to set constraints on their inversions thus limiting the solutions to their geophysical problem to a suite of realistic Earth models.

Objective Function
When geophysicists wish to invert data to obtain a model, they must pose an optimization problem in which the data misfit and model norm are cast into a single objective function (the sum of the data misfit with the product of the tradeoff parameter and model norm). The inverse problem thus becomes a question of finding the Earth model that minimizes the objective function. In the UBC MAG3D software, the user can specify four parameters (alphas, alphax, alphay, alphaz) which are meant to control the level of emphasis on each part of the model objective function.

Optimization
A branch of mathematics related to determining the best or optimum choice from a large (possibly infinite) range of possibilities.

Physical Properties
In the context of geophysics, physical properties refer to the physical characteristics of the ground being investigated, such as density, electrical conductivity, and others.

Potential Field
A field that obeys Laplace's equation, such as gravity, magnetic, or electrical fields. For such fields, the vector field may be expressed as the gradient of some scalar potential or the curl of a vector potential.

Predicted Data
These are the synthetic data produced when forward modeling is applied to predict the values of what measurements would be if a geophysical survey was carried out over a given model (a representation of the subsurface).

Reference Model
A model, often a "best guess" built up from limited a priori information about the composition of the Earth in the region of interest (could be as simple as a uniform halfspace or incorporate more detailed geological observations), that is used as a starting point to constrain an inversion.

Regional Signal
In geophysical exploration, in particular gravity and magnetic methods, we are most often looking for spatially narrow anomalies that might be the signature of subsurface deposits or related structures. In many such cases the signal from larger scale, "regional," sources might obscure that of the exploration targets we are interested in locating. As such, it is often prudent, and indeed necessary, to estimate the part of the signal from "regional" sources in order to subtract this from the observed data to yield residual data that better reflects the anomalies produced by spatially limited exploration targets.

Regularization
The data are finite number of inaccurate observations, therefore there are many more model parameters (or cells) than data and we don't want to produce a model that will exactly reproduce the data. As a result the data don't uniquely constrain all of the model parameters and there are an infinite number of models that, when forward modeled, will reproduce the data to within the specified standard deviations. This inherent instability is regularized through the introduction of a model objective function which enables us to choose the type of model recovered. In this function a priori information can be applied in the form of constraints. In the absence of any a priori information the smallest or smoothest models are recovered. Flexibility of this function through control parameters (alpha coefficients and weighting matrices) ensures that most geologic scenarios can be achieved. There is a trade-off between the degree to which the data are fit and the influence of the model objective function. This means that if the data predicted from the model closely reproduces the observed data, noise in the data maybe manifested as spurious features in the model. Whereas if the predicted data does not reproduce the observations well the model assumes the characteristics of the a priori information. These situations are termed over-fitting and under-fitting the data respectively. This trade-off is generally manipulated with the Chi-factor which controls the degree to which the data is fit. If it is assumed the data have errors that are Gaussian in nature, have zero mean and are non-correlative in nature, when the errors have been appropriately assigned a data misfit equal to the number of data would produce the best result. The Chi-factor is the ratio of data-misfit to number of data; a Chi-factor of less than one would over-fit the data while a Chi-factor of greater than one would under-fit the data. Convergence of an inversion is obtained when a reasonable model is determined while fitting the data to the prescribed degree.

Remanent Magnetization
Remanent magnetization (or remanence) is a permanent magnetization that can be obtained by ferromagnetic material through several phenomena including thermo-, chemical and detrital remanence.

Often, the remanence obtained in the past becomes oriented in a direction different from the Earth's field today; this can occur through movement of the Earth's magnetic poles or through tilting of the stratigraphic units containing the permanently magnetized material.

Residual
In the broadest sense, we can think of the "residual" as the result of the subtraction of any two sets of values. If we take the difference between observed and predicted data, the resulting "residual" provides a quick measure of how well we did in estimating the predicted data (i.e., how well do the predicted data match the observed data). We might also consider the difference between our observed data and our estimated regional data. What is left over can be referred to as a "regional residual." Had we taken the difference between our reference model and our inverted model, we would be left with our "model residual."

Resistivity
The property of a material that resists the flow of electrical current. The reciprocal of resistivity is conductivity. Units: ohm meter.

Self-Demagnetization
For high magnetic susceptibilities (> ~0.2 S.I) the relationship between the strength of magnetization and susceptibility is non-linear. This non-linear relationship is the cause of the phenomena known as self-demagnetization where a component of the magnetization opposes the Earth's field.

Standard Deviation
Standard deviations represent the uncertainty of, or error in, the data and are an integral part of the survey. They have to be provided for each datum in order to determine the degree to which the model should reproduce, or fit, the data.

Terrain-corrected Gravity
The value obtained after latitude correction, elevation correction (including both free-air and Bouguer corrections), Eötvös correction (for marine and aerogravity), and terrain correction have been applied to gravity data. Also called Bouguer Gravity or Complete Bouguer Anomaly.

Terrain Correction
1. A correction to gravity data required because the surroundings are not all at the same elevation as the meter. Relief in the immediate vicinity of the station may require special terrain surveying, whereas corrections for more remote relief often are made from a topographic map using a terrain-correction template or zone chart. 2. A correction to seismic data because of the effect of topographic loading on velocity. 3. A correction to magnetic or electrical data because of terrain effects.

Time Domain Electromagnetic Method (TDEM)
An electromagnetic method in which the waveform of the transmitted signal is a train of pulses, step-functions, ramps, or other waveforms, and measurements are made in the off-times between pulses, usually after the primary field has stopped changing. Principal advantages of transient methods over continuous-wave methods are that the primary field is not present during the measurement of the secondary field and that measurements of the secondary field as a function of time are equivalent to continuous-wave measurements over a wide frequency range. Transient methods are used for both depth sounding and continuous profiling.

Topography
In terms of inversion, if topography is being included it should be provided for the whole area being considered and with a data density appropriate for the scale of discretization (i.e. at least one value per mesh cell).

Total Magnetic Intensity (TMI)
Sometimes referred to as total magnetic field strength, in the context of geophysics, the total magnetic intensity is a measure (SI Units: nanoTesla or nT) of the magnitude of the Earth's magnetic field at a given location. Since the total magnetic intensity is inversely proportional to cube of distance, it drops off rapidly as we move away from the source. Local deviations from the expected total magnetic intensity at a given location are caused by anomalous bodies (e.g., exploration targets, cultural artifacts, etc.) and form the basis for geomagnetic surveys.

Trade-off Parameter
When we minimize the misfit in an unconstrained optimization problem, we minimize the sum of the data misfit and a scaled version of the model norm. The scaling factor, beta, also known as the regularization parameter or trade-off parameter, controls the relative weighting between the model and data misfit

Unconstrained Inversion
Unconstrained inversion refers to the calculation of a susceptibility model that is not guided by the input or reference to known geologic or petrophysical information. The results are based simply on a best fit model of the input data.

Under-determined
A problem is said to be under-determined when there are more unknowns than data. There are not enough equations to obtain a unique solution. Under-determined problems are inherently "non-unique". *See Non-uniqueness.*

Weights
Often we may wish to have control on how much influence a particular part of the model has on the inversion. We do this through assigning weights to control the relative importance of any given cell with, for example, depth (need for potential fields) or distance. In addition, when we minimize the misfit in an unconstrained optimization problem, we minimize the sum of the data misfit and a scaled version of the model norm. The scaling factor, beta, also known as the regularization parameter or trade-off parameter, controls the relative weighting between the model and data misfit.

Workflow
We use the term "workflow" to describe both the conceptual sequence of steps followed by domain experts to discover solutions to geoscience business challenges, as well the specific software interfaces that embody them. Software workflows are applications designed to execute a sequence of modelling tasks via a dynamic user interface presented in the appropriate earth science terminology.