KMS Technologies – KJT Enterprises, Inc.

Appendix 3
Useful Information

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Appendix 3
Useful Information

GLOSSARY

A-type curve – an apparent resistivity curve exhibiting an increasing resistivity for a 3-layer model: ($\rho_1 < \rho_2 < \rho_3$)

Analog modeling – in order to simulate the real geologic situation, a model can be built in the laboratory using metal or other materials. When scaling down the geometry the conductivity must also be scaled to simulate as close as possible the field situation. This type of scale modeling is called analog modeling.

Archie's formula – an empirical formula relating the resistivity of a formation with the resistivity of the formation fluid, the formation porosity and the pore space filled by the pore fluid. The constants associated with this formula are empirical and may change with rock type. Archie's law should only be applied to single member rocks (i.e. clean sand).

Anisotropy – a volume element is electrically anisotropic when the resistivity of a layered medium is different in horizontal and vertical direction, i.e. the medium has different longitudinal and transverse resistivity. A sedimentary layer-cake is typically anisotropic due to its depositional history.

Bipolar continuous waveform – see *current waveform*

Bipolar waveform – see *current waveform*

Calibration factor – a constant which for the magnetic components of TEM only depends on the distance between transmitter and receiver. This factor can be used to compensate for inaccuracies in field parameters as well as corrections due to current channeling and static shifts.

Coefficient of anisotropy – the square root of the ratio of vertical and horizontal resistivity $\sqrt{\frac{\rho_v}{\rho_h}}$

Clock rate – time length of one clock pulse or time between clock pulses. Typically the clock rate is half of the repetition rate.

Conductance – see *total conductance*.

Conductance referencing – a correction procedure where the total conductance of a layer or layer–cake is kept fixed and the thickness and resistivity are adjusted. Usually, the resistivity is selected to be the average resistivity and the thickness is adjusted accordingly keeping the total conductance to be the same.

Controlled source electromagnetics – a terminology grouping all electromagnetic techniques which use their own transmitter. Examples are transient electromagnetics (TEM) and controlled source audio EM (CSAMT).

CSAMT – Controlled Source Audio Magnetotelluric method. A technique similar to magnetotellurics in the audio frequency range (1 Hz to 20 kHz) using as source excitation a transmitter which is at least five times the skin depth away from the receiver.

Cumulative conductance – see *total conductance*.

Cultural noise – electromagnetic noise caused by man and the effects of industrialization and civilization (i.e. power lines etc).

Current waveform – the shape of the current as a function of tune as injected by the transmitter. To avoid effects caused by the polarization of the electrodes for LOTEM a bipolar waveform is being used. This waveform has the shape of a positive and negative square wave separated by an off–time. A bipolar continuous waveform is obtained when the off–time is negligible (polarity reversing transmitter).

Electrical anisotropy – see *anisotropy*.

EM 37 – shallow transient EM system developed by Geonics Ltd. of Canada.

Equivalence – see *layer equivalence*.

H–type curve – An apparent resistivity curve exhibiting a decrease resistivity second layer ($\rho_1 > \rho_2 < \rho_3$).

Inversion – a procedure to derive from the field data an earth model which is consistent with the data and describes the subsurface.

Joint inversion – when inverting two independent data sets simultaneously to obtain one resulting model, one calls this process joint inversion. Usually the data vector has the length of both data sets while the model parameter vector remains of the same length as for ordinary inversion methods.

K–type curve – An apparent resistivity curve exhibiting an increase resistivity of the second layer ($\rho_1 < \rho_2 > \rho_3$).

Layer–cake – a combination of different layers building one unit. Typically used in sedimentary environment because of its depositional process.

Layer equivalence – a procedure to reduce a multi–layer model (derived from a well log) to a simpler model containing less layers. Usually the thickness of the layers, h_i, is maintained. Then from the total thickness, H_T, the average resistivity is calculated using a formula derived from the total conductance.

LNC – Local Noise Compensation technique. A noise compensation

$$\rho_{average} = H_T \Big/ \sum_{i=1}^{n} \frac{h_i}{\rho_i}$$

method using a base station to obtain a high quality base stack. This is then used to calculate the noise for the entire measuring time. The noise of the base station is then subtracted from the individual records of a mobile receiver. This technique can only be used, when the noise at the base station and at the mobile receiver is correlated (spatially constant).

Longitudinal resistivity – The resistivity of a medium measured with horizontal current flow. The resistivity in lateral direction.

LOTEM – Long Offset Transient ElectroMagnetics. A transient electromagnetic sounding technique using an earthed wire transmitter and several components of the electromagnetic field at the receiver which yield independent information on the resistivity structure of the subsurface.

Magnetotellurics – an electromagnetic depth sounding method using the natural electromagnetic fields as source and measuring 5 components (H_x, H_y, H_z, E_x, E_y) of the electromagnetic field.

MT – see *magnetotellurics*.

Nonseismic methods – a terminology referring to the geophysical techniques used for oil exploration other than reflection seismics (i.e. gravity, magnetics, electromagnetics etc.).

Offset – distance between transmitter and receiver center position.

Off–time – the time between current switching when no current is flowing in the transmitter

PRBS – Pseudo Random Binary Sequence; an electromagnetic technique where the transmitter signal code in a PRBS fashion. The intention of this technique is to overcome the noise in the same manner as done with vibroseis in reflection seismic (see Duncan et al. 1980).

Q–type curve – an apparent resistivity curve showing a decreasing resistivity for a 3–layer model: ($\rho_1 > \rho_2 > \rho_3$).

Periodic noise – electromagnetic interference noise caused by power lines from the AC grid and AC railroad. The noise is of sinusoidal nature and can usually be filtered out by digital filters or analog notch filters during recording. In general geophysics called "high–line noise".

Ramp time – the time the transmitter current requires to go from one constant current state to the other.

Repetition rate – the full cycle between source signals of the same shape and polarity.

Reversal – the term reversal describes a transient signal which crosses the reference DC–level during signal duration. Reversals are not theoretically possible for layered structures for the LOTEM H_z component and are indicative of faults, pipelines and the like.

SIROTEM – shallow transient EM system developed by the Scientific and Industrial Research Organization of Australia.

Spitter – a mechanical device used to pick up wire while driving. A spitter is a common device for seismic and deep EM cable crew. Similar devices are also used in several countries in a reversed mode to eject rubber bullets.

Sporadic noise – electromagnetic noise. It can be seen on the recorded trace as a spike. This type of noise is caused by pumps, machinery, surges on the AC grid and others.

Static shift – in electromagnetics analogous to seismic distortion of the data caused by near surface inhomogeneities. Strictly speaking static shift refers to shifts of the curves (mainly in amplitude) which can be interpreted with a model different from the true earth. Since this is usually not known before the interpretation, sometimes one refers to 3–D distortions as static shifts.

System response – the response of the acquisition including transmitter and receiver component to an ideal spike input signal. The output signal as recorded y(t) consists of the system response sy(t) convolved with the input signal x(t): $y(t) = sy(t) * x(t)$

TDEM – Time Domain ElectroMagnetics. see *TEM*.

TEM – Transient ElectroMagnetics. An electromagnetic technique in the time domain. using a transmitter to generate a secondary electromagnetic field in the subsurface. This secondary electromagnetic field is being measured when no additional induction currents are being generated.

Total conductance – the integral conductance of a layer–cake, i.e.

$$S = \int_0^z \sigma \, dz$$

Transverse resistance – The resistivity of a medium for currents crossing the layer boundary.

Transverse resistance referencing – a correction procedure where the transverse resistance of a layer–cake is kept fixed and the thickness and resistivity are adjusted. Compare *Conductance referencing*.

UTEM – University of Toronto EM system. A transient EM sounding and profiling system developed at the University of Toronto and now being primarily used by Lamontagne Geophysics Ltd. of Canada. See *TEM*.

Walkaway test – test measurement usually carried out to check out the transmitter quality. Selected receiver sites are usually measured perpendicular to the center of the transmitter starting at a few hundred meters and changing in offset up to several tens of km.

Z – transform – The Z – transform may be thought of as $Z = e^{i\omega t}$, which is an easy way to relate time to a domain that can be similarly treated as the frequency domain (Sheriff, 1984).

LOTEM FIELD OBSERVER'S LOG   SINGLE SITE SYSTEMS

DATE:	SOURCE CODE:	STACKED DATA FILE NAME:
PROJECT:	LENGTH: m	SAMPLING RATE: Hz
CREW CHIEF:	CURRENT: A	AMPLIFIER S/N:
OPERATORS:	CLOCKRATE: sec	PREAMPLIFIER S/N:
SYSTEM:	BEARING: EX: EY:	CLOCK S/N:

TX – COORD.	ELECTRODE 1 x:	ELECTRODE 1 y:	ELECTRODE 2 x:	ELECTRODE 2 y:

CURVE ID	coordinates			AMPLIFIER Gain		AMPLIFIER Notches		LP	BC	PREAMPLIFIER Gain			PREAMPLIFIER Notches		LP	BC	Rec.	Time		Samp rate	PROCESSING SYSTEM
(i.e. 01ABHZ)	X	Y	ELEV. (Z)	N	M	50	16 2/3			N	M	P	50	16 2/3			code	in	out	Hz	response name
COMMENTS:																					
COMMENTS:																					
COMMENTS:																					
COMMENTS:																					
COMMENTS:																					

CLOCK DRIFT MEASUREMENT LOG

Survey Area: ____________ | Operator: ____________ | Date: ____________

Crew Chief: ____________

Master clock: used as reference: ____________

synchronize at: ___ ___ ___ ___ ___ , file name: ____________

day month year hour min

SYSTEM A:

Synchronization at:

___ ___ ___ ___ ___

day – month – year hour – min

Clock rate (sec): ____________

file name: ____________

Measurement of clock drift at:

___ ___ ___ ___ ___

day – month – year hour – min

Drift (ms): ____________

Calculated Accuracy per second: ____________

SYSTEM B:

Synchronization at:

___ ___ ___ ___ ___

day – month – year hour – min

Clock rate (sec): ____________

file name: ____________

Measurement of clock drift at:

___ ___ ___ ___ ___

day – month – year hour – min

Drift (ms): ____________

Calculated Accuracy per second: ____________

Signature of Operator: ____________

FILE CONVENTION: **AF01A1.CL1**

- survey code
- receiver code
- day of survey (starting at 01)
- transient code, increments for different settings, repeats etc.
- clock # of trigger source
- clock drift measurements
- clock # of signal source

LOTEM TRANSMITTER RECORD SHEET

Project: ______	Operator: ______	Date: ____.____.199_
Transmitter: ______	Crew Chief: ______	

CHART-RECORDER

voltage				speed	
10 mvolts	☐	1 volt	☐	2	☐
20 mvolts	☐	2 volts	☐	6	☐
50 mvolts	☐	5 volts	☐	20	☐
100 mvolts	☐	10 volts	☐	60	☐
200 mvolts	☐	20 volts	☐		
500 mvolts	☐	50 volts	☐	cm per hour ☐	cm per min. ☐

GENERATOR

Type: ______ kVA		3 phases ☐
Output: ______ Volts		1 phase ☐
Cycles: ______ Hz		

CHECK LIST

Cooling of switchbox	☐	2 cables from electrodes	☐
Remote control	☐	Clock connection	☐
Power cable	☐	Generator not grounded	☐

RUNNING TIME

time on	time off	comments

CURRENT RECORDING

time	High (+)	Low (-)	comments
08.00	______ Ampere	______ Ampere	
09:00	______ Ampere	______ Ampere	
10:00	______ Ampere	______ Ampere	
11:00	______ Ampere	______ Ampere	
12:00	______ Ampere	______ Ampere	
13:00	______ Ampere	______ Ampere	
14:00	______ Ampere	______ Ampere	
15:00	______ Ampere	______ Ampere	
16:00	______ Ampere	______ Ampere	
17:00	______ Ampere	______ Ampere	
18.00	______ Ampere	______ Ampere	

Inversion Statistics

There are several ways to evaluate the reliability of the inversion result. For LOTEM we have found that the SVD analysis works best. In particular, the inversion statistics allow full adjustment to the sensitivity of the LOTEM method and are thus particularly suited. In the development of inversion statistics we followed closely the paper by Raiche et al (1985) and Jupp and Vozoff (1975). As an example of what the individual parameters mean we give a description of the statistics below. In the interpretation chapter 4 we refer to these statistics in many different places.

The following is the explanation for the statistics output from the inversion program we use. The list is in alphabetical order and included here because the terminology is needed for the following inversion examples.

APRE – The average predicted residual error (APRE) is used to determine the model with the least number of layers which is still consistent with the data. For this model, APRE has a sharp minimum compared with the models with more or fewer parameters.

Confidence bounds – Confidence bounds for the physical parameters can be obtained by tracing back the uncertainties in the measured data towards the physical parameters. They are the same for the physical parameters what the damped error multipliers are for the eigenparameters. The standard deviation of the fit is taken as the uncertainty of the data. When calculating the *confidence bounds* it is advisable to use 95% confidence intervals for data with high signal to noise ratio and 68% for noisy data. Also when calculating the *confidence bounds*, for LOTEM for deep applications, one should calculate them with damped multipliers (Cramer–Rao Multipliers). This means that only the well resolved parameters will be varied and not randomly all parameters.

Correlation matrix – This symmetric N by N matrix shows the correlation between any two parameters. The correlation matrix is calculated from the covariance matrix of measurement and theoretical curve.

Covariance matrix – The covariance matrix indicates, how the fit between the calculated curve ('solution') and the measured curve ('data') transforms into confidence bounds for the solution.

Cramer–Rao multipliers – The Cramer–Rao multipliers for the original parameters transform the fitting error between data and calculated curve over to confidence bounds for the physical parameters. They are the same for the physical parameters what the (damped) error multipliers are for the eigenparameters. In fact they are obtained from the (damped) error multipliers through a transformation back into the physical parameter space. This may be done damped or undamped.

Deviation of mean – The standard deviation of mean value shows, how good the mean of each data point is in relation to the calculated value. This factor gives an estimate of the statistical probability of the calculated values.

Damping factors – The damping factors indicate the influence of the transformed parameters (eigenparameters) on the calculated curve. They show more directly the influence of the corresponding parameter combination on the curve than the spectral values (or singular values SV).

Damped error multipliers – The damped error multipliers for the transformed parameters are calculated as the ratio of the damping factor divided by the the spectral value (singular value, SV). They are used in the calculation of the correction vector for the eigenparameter during each iteration (if damped error bounds were selected in the inversion setup). Hence they indicate the change of the parameters during the last iteration. When the program has converged properly onto a solution then these multipliers should be small for all parameters. If they turn out to be large, then the convergence criterion was probably set too high so that the program stopped even though there had been clear changes in the parameters.

Importance – The importance of the physical parameters is also called 'damping factors of the original parameters' in the statistics output of the inversion program. They are nothing more than the damping factors of the eigenparameters transformed back into the physical parameter space. Hence, they give the influence of the real parameters on the solution and are therefore called 'importance' of the parameters. They are a tool to judge the reliability of a parameter which has resulted from the inversion (see also 'damping factor' and 'normalized spectral value' or 'normalized singular value', SV).

Inverse Jacobian – The generalized inverse of the Jacobian matrix is also called 'data influence matrix'. It indicates how a small change in the measured data would influence the inversion result without actually doing another inversion. This matrix is therefore of interest for the inversion of synthetic data during a feasibility study and survey design.

Jacobian– The normalized Jacobian matrix is a measure for the change in the i–th data point, when the j–th parameter is varied. Hence this matrix is also called parameter influence matrix or sensitivity matrix. A parameter is only well resolved by the measurement if the data points depend strongly on this parameter, in other words: if the Jacobian has large entries in the corresponding column. Furthermore, each column of the Jacobian indicates the time window, in which the corresponding parameter is predominantly resolved by looking at the variation in the data. The columns are ordered thus: first the resistivities, then the thicknesses, then (in the joint case) the calibration factor(s). If you do a joint inversion MTHZ, the entries in the calibration factor column must be zero in the part which belongs to the MT data. The same applies to HZEX and HZEY.

Noise–to–signal ratio – The noise–to–signal ratio (NSR) is a measure for the quality of the data. It shows how well the inversion algorithm can pick up variations of the data from the model. The NSR is calculated from the standard deviation, the number of data points, number of parameters, the model data and their mean value.

Number of effective parameters – The number of effective parameters is calculated as the sum over the damping factors. It shows how many parameters can effectively be resolved. The fewer parameters contribute to the solution, the smaller is this number. On the other hand, if all parameters are important then this number of effective parameters should be only slightly smaller than the actual number of parameters.

Number of iterations – The number of iterations that were completed before convergence. Linear problems would converge after just one iteration. The higher the non–linearity of the problem, the more complicated is the correlation among the parameters. This requires more and more iterations. The number of iterations depends also on the number of the parameters and the starting model.

Scale factor – The scale factor is defined as the largest SV. It allows to obtain the true values from the normalized values by a simple multiplication.

Spectral values – The normalized spectral values (SV, also called Singular Values from the Singular Value Decomposition, SVD) are a measure for the importance of the corresponding combination of N parameters for the solution. If the normalized SV is greater than about 0.1 then the corresponding damping factor is close to 1.0 and the corresponding parameter combination strongly influences the solution. If the normalized SV is much smaller than 0.1 then the damping factor becomes very small and it is dominated by the Marquardt factor. The corresponding parameter combination looses its influence on the calculated curve and hence it becomes unimportant. The ratio between the biggest and the smallest SV is a measure for the condition of the Jacobian matrix just as in any true eigenvalue problem.

Standard deviation – The standard deviation is a measure for the difference between the model curve and the data curve. It is a measurement for the goodness of fit of the two curves.

U – matrix – The U–matrix contains the eigenvectors of the data space. The product U times its transpose gives the information content of each measured data point.

V – matrix – The V–matrix sets up the relation between the physical and transformed parameters. Its columns are the eigenvectors of the parameter space. These eigenvectors represent combinations of the physical parameters (thickness, or resistivity). We consider only the logarithms of the resistivity and thicknesses. Each of the eigenvectors indicates which combinations of parameters are resolved. For example, suppose the entry for the thickness of the second layer is large positive (0.7) while the entry for the resistivity of the second layer is large negative (–0.7). Since we consider logarithms, this means that the conductivity – thickness product of the second layer is resolved with this eigenparameter. However, if the eigenvalue (singular value, SV) of that eigenparameter is small, then the eigenparameter does not contribute much to the solution – in other words, it is not important. Which combination of parameters contributes to the solution (that means which eigenparameter is actually resolved) can be only seen from the corresponding eigenvalue or SV and the damping factor which is calculated from the SV.

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