KMS Technologies – KJT Enterprises Inc.

Chapter 6
Survey Feasibilitiy Studies

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Chapter 6
Survey Feasibility Studies

This chapter describes two main tasks during the preparation of a LOTEM survey: *feasibility studies* and *survey design*. The same kind of work is done for both tasks but the aims are different:

The feasibility study determines whether or not a specific exploration problem can be solved with the LOTEM method. Once this is decided positively, the same tools that were used for the feasibility study are now used to design a survey and to optimize the survey parameters such as transmitter – receiver distance (offset) and time window for the data acquisition.

The first step is the construction of a simple geoelectric model consisting of layers with thicknesses and electrical resistivities assigned to each layer from a well log or other geophysical *a priori* information. Next, each of the thicknesses and resistivities is changed within a reasonable range. For each of the changes, LOTEM field data are simulated and compared. If the curves are different, then there is a chance to detect the changes and in many cases also the actual values of thickness or resistivity.

Two types of feasibility studies are shown for real field situations. The first case history is a synthetic example for a field situation from China where a thick carbonate unit at a depth between 4 to 6 km had to be resolved. The second case history uses real exploration data as input for an investigation in an production environment in Australia. The last case history considers the possible application of LOTEM to an exploration problem in Japan.

SURVEY DESIGN BASED ON WELL LOGS

The goal of the reduction of electrical logs to obtain a suitable model for the LOTEM method is:

Using the given detailed log of resistivities and depths (e.g. from well logs), derive geoelectric boundaries and equivalent resistivities such that they can be resolved with the LOTEM method.

- First, the emphasis should be on finding the simplest geoelectric model (least number of layers) that is resolvable with LOTEM and at the same time is the best representation of the geology.

- Second, you can incorporate other geophysical knowledge (such as structural information from seismic interpretation) to refine the layering and test the resolution using inversion techniques in your synthetic data.

In most cases there will be at least one well log of electrical resistivity available for the target area. Well logs have usually a much finer resolution of layers than can ever be expected from an electromagnetic surface method. In order to estimate the resolution capability of the particular surface method (in our case the LOTEM sounding method), the well log must first be reduced to an electrical model with only a few layers of different resistivities.

A reduction is basically an average and the way this average is calculated, introduces a bias into the subsequent resolution analysis. There are two ways to control this bias:

- Use simple layer equivalencing where the thickness of the layers is kept fixed and an average resistivity is being calculated. The procedure is designed so that the resulting reduced model is well adapted to the intrinsic resolution capabilities of LOTEM. This facilitates a subsequent resolution analysis greatly.
- In difficult cases, use an iterative procedure between layer equivalencing and forward modeling to optimize the reduction before you commence with the resolution analysis.

The following example illustrates the use of the layer equivalencing technique. We assume that a well log has already been blocked to reduce the number of data points normally contained in a digitized well log. The first blocking is usually done by maintaining the lithological boundaries as much as possible. Table 6.1 shows an example where from the well log the blocking was done based on the lithological boundaries. A graphic display of the blocked well log (squares) and the reduced models for a four layer and five layer case are shown in figure 6.1.

Table 6.1: Example for a simplified electric well log: resistivities, thicknesses and lithology.

Formation	Depth (m)	Resistivity Range (Ohm-m)	Average (Ohm-m)	Thickness (m)	Lithology
CRETACEOUS	0 – 101	20 – 100	30	101	SS
	101 – 285	33 – 86	50	184	SS
JURASSIC	285 – 335	35 – 230	100	50	marly LST
	335 – 1316	120 – 13000	3000	981	volcanics
TRIASSIC	1316 – 1700	200 – 800	600	384	SH,ANH
	1700 – 1750	15 – 60	50	50	SS
	1750 – 2050	400 – 2000	900	300	DOL,LST
	2050 – 2210	15 – 80	60	160	SS (target)
PERMIAN	2210 – 2480	100 – 600	150	270	SS (target)
PALEOZOIC	2480 – ...	20 – 2000	1500		granites

LST=limestone, SS=sandstone, DOL=dolomite, ANH=anhydrite, SH=shale

The values of depth and resistivity of the induction log are then used to calculate the *cumulative conductance*. The *cumulative* or *total conductance* of a layer-cake is obtained from:

$$S = \frac{H_T}{\rho_{average}} = \sum_{i=1}^{n} \frac{h_i}{\rho_i} \tag{6.1}$$

H_T is the added thickness of all layers (total thickness), ρ_i and h_i are the resistivity and thickness of the selected piece of the layer-cake and $\rho_{average}$ the average resistivity to be used in the modeling (Keller and Frischknecht, 1966). This resistivity is obtained under the assumption that the *total conductance* for the layers averaged remains constant. We obtain:

$$\rho_{average} = \frac{H_T}{\sum_{i=1}^{n} \frac{h_i}{\rho_i}} \tag{6.2}$$

Other ways of averaging such as using the *transverse resistance* or weights for the parameters can be applied, where necessary.

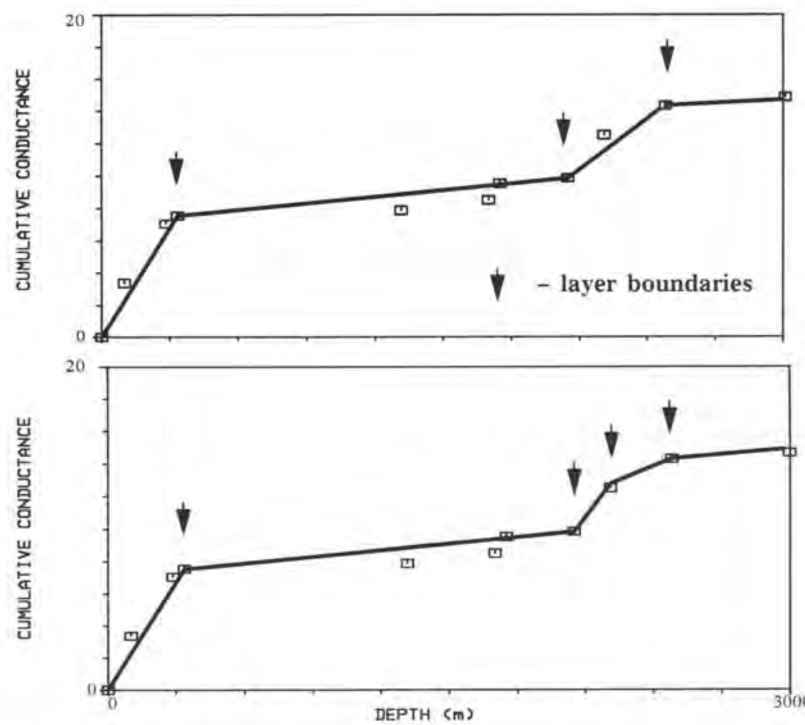


Fig. 6.1: *Cumulative conductance* for the blocked well log from table 6.1 for a four-layer model (top) and a five-layer model (bottom).

Most electromagnetic methods resolve just this function and not discrete layers of constant resistivity. The slope of this function is the resistivity and bends in the curve (if present) indicate layer boundaries. Reducing the well log further for use in LOTEM forward modeling consists in the following steps:

- Fit a few straight lines to this curve.
- Define the slopes of the lines as the resistivities of the layers.
- Define the intersections of the lines as the layer boundaries.

These steps can be done by hand or using simple computer programs. In table 6.1 the results of the coarse blocking of an electrical log is summarized. The lithology and resistivity ranges are also given to allow the interpreter to check the plausibility of the results. Table 6.2 lists the further reduced model obtained after layer equivalencing.

Table 6.2: Reduction models resulting from different degrees of reduction of the geoelectric model. Left: five-layer model, right: four-layer model.

5 LAYER MODEL			4 LAYER MODEL		
Layer No.	Resistivity (Ohm-m)	Thickness (m)	Layer No.	Resistivity (Ohm-m)	Thickness (m)
1	44	335	1	44	335
2	748	1715	2	748	1715
3	60	160	3	96	430
4	150	270	4	1500	
5	1500				

Figure 6.2 demonstrates the effect of the reduction process by displaying the synthetic curves for the models with 10 and 5 layers. Although the two modeled geoelectric sections are quite different, they give almost the same results. In fact, the differences between the two simulated data curves between 1 ms and 3 ms are outside the measurable time window. It will be difficult to resolve the difference between the complicated model and the simple model. On the other hand, the complicated model simulation requires much more CPU time for the calculation which would make the sensitivity studies time consuming and ambiguous. The normal procedure would be to continue the feasibility study with the reduced geoelectric model.

The following is an example for a case, where layer equivalencing and the forward modeling program MODALL (see Appendix 4) are used in conjunction to check the validity of the five-layer model. As can be seen on the cumulative conductance curves in figure 6.1, the two separate target layers have almost the same slope. The question arises whether they are resolved as two individual layers or only as one unit. An equivalent model could be found that contains only one target unit with a resistivity averaged from the two target layers (compare table 6.2). This model can be compared with the five-layer model previously derived. The result in figure 6.3 shows that the target is resolved only as one unit, because the curves using a five- or four-layer model cannot be distinguished.

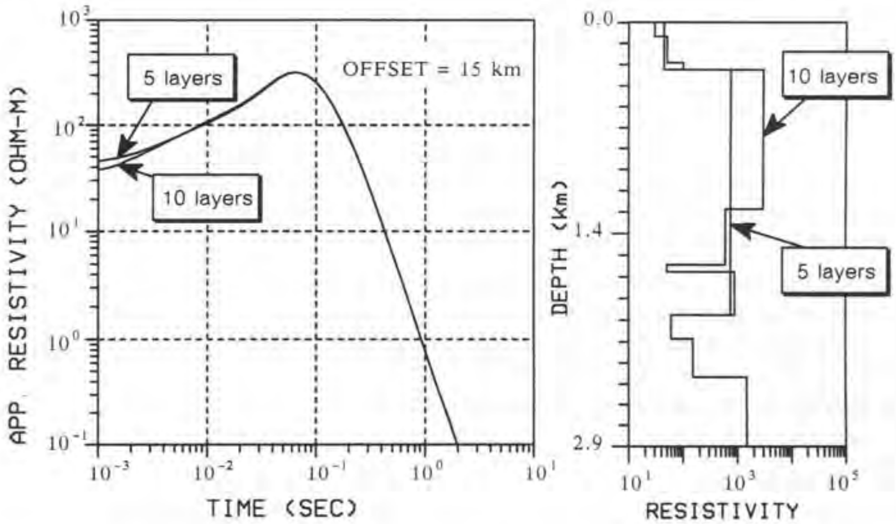


Fig. 6.2: Simulated LOTEM data for the blocked model without reduction (10 layers) in comparison with the reduced model (5 layers).

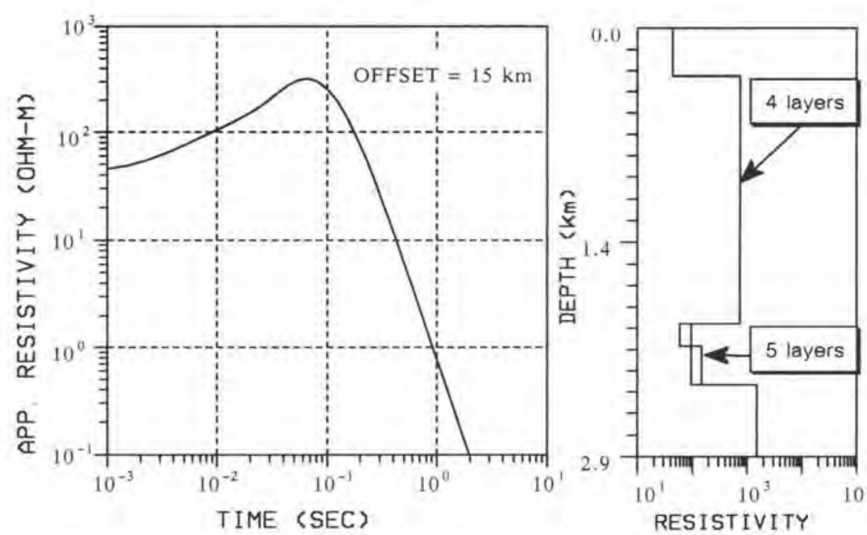
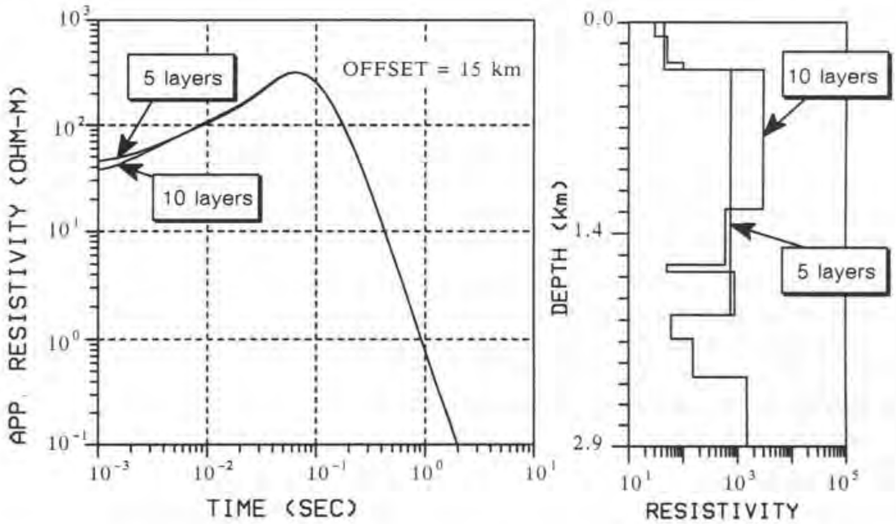


Fig. 6.3: Simulated LOTEM data for the two different reduction models (5 layers and 4 layers).

As consequence one should use a five-layer model for the sensitivity study because it is easier to assign realistic resistivity variations to each of the two geological target layers separately than to derive variations of the average resistivity of the combined units. The geophysicist/geologist must however keep in mind, that the variations he



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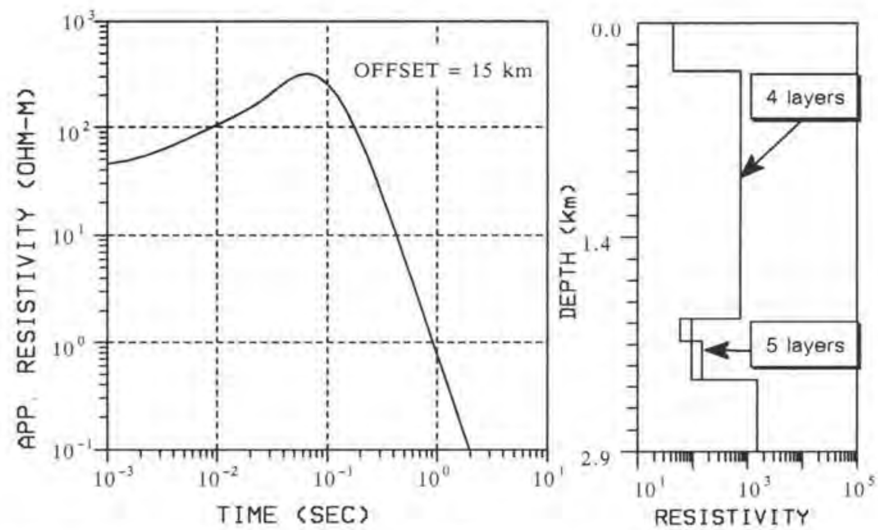

Fig. 6.3: Simulated LOTEM data for the two different reduction models (5 layers and 4 layers).

As consequence one should use a five-layer model for the sensitivity study because it is easier to assign realistic resistivity variations to each of the two geological target layers separately than to derive variations of the average resistivity of the combined units. The geophysicist/geologist must however keep in mind, that the variations he introduces in one of the two target layers could just as well be replaced by similar variations in the other one. In other words: *the two target layers in this example are not resolved as individual units but only as a whole.*

Forward modeling is used to determine how sensitive the method is for variations of thickness or resistivity of any layer in a given model. Starting from a basic model each of the thicknesses and resistivities is changed within a reasonable range. For each of the changes, noise-free LOTEM field data are simulated and compared. If the curves are different, then there is a chance of detecting the changes and in many cases also the actual values of thickness or resistivity.

The second task for forward modeling is the design of the actual field survey. Variations in the transmitter-receiver offset are used to find the optimum value of the offset. Calculation of the expected signal levels gives a limit to the natural electromagnetic noise that can be tolerated with the available equipment. In practice the signal levels determine the maximum transmitter-receiver offset because the signals (voltages) decrease with offset.

The computer program MODALL is used for both these tasks. The program is menu-driven and self-explanatory so that the description is only required for difficult questions (see appendix 4).

Varying the transmitter-receiver offset is the first step in the analysis. In some cases it is obvious from the simulated curves in which time window the effect of the target layer occurs – especially in the case of a pronounced conductor. Since this is not the rule the following example does not have this feature. The optimum offset in this example can only be decided after a few of the other parameters have been investigated.

Figure 6.4 shows apparent resistivity curves for the complicated ten-layer model from the previous section at three different offsets. For this case, no features of the electric model can be seen in the generated curves except for the slight influence of the conductor in the early time curve (around 30 msec) at 15 km offset. To be slightly conservative, an offset of 10 km was selected. Further modeling is required before making the final decision for time window and for the offset used in the field.

Thus, when actually starting a survey in the field, the first activity should always be a *walkaway test*. This is a series of measurements starting at the transmitter and moving to the offset distance planned for the survey. This *walkaway test* should always start close to the transmitter and end at the distance of the desired profile or even further. The data recorded on a walkaway profile yield several different answers:

- It shows how the noise varies with offset and what system parameters (gain, number of stacks) should be used.
- If a significant 2-D or 3-D structure exists between transmitter and receiver, it will usually be seen as reversal in the *walkaway test*.
- For smooth 2-D or 3-D structure the measurements of both electric field components on the walkaway profile can give you some preliminary indication of the strike direction (current channelling) of the structure.

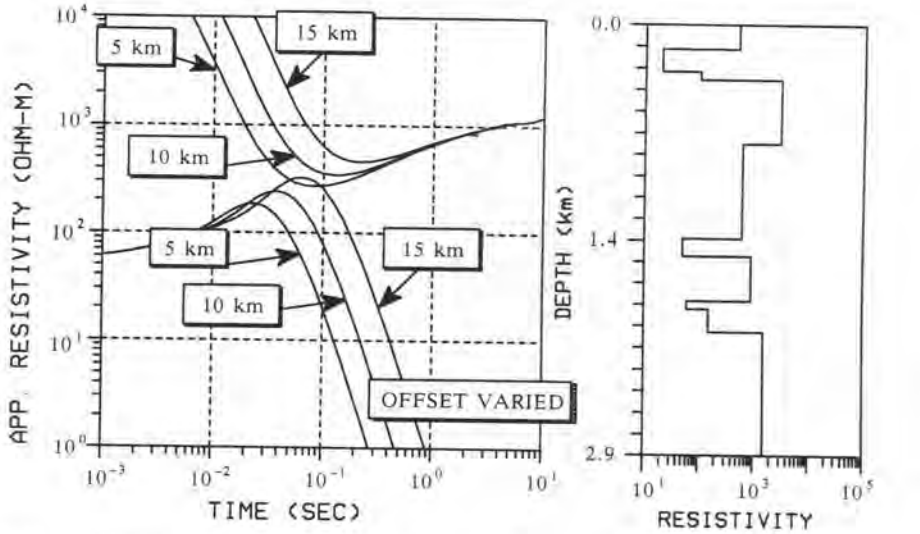

Fig. 6.4: Apparent resistivity curves for three different transmitter–receiver offsets (5, 10 and 15 km) for the ten–layer model.

Next, the resistivity of the lower target layer was varied within the range from 100 to 600 Ωm (see table 6.1). The result in figure 6.6 shows that this parameter is resolved, but the calculated curves do not vary as much as the curves in figure 6.5 for the thickness variations of the first target layer.

Examples for parameter variations are shown in the following figures (figure 6.5 to 6.7). First, in figure 6.5, the thickness of the upper part of the target was changed from 1 m (simulating the absence of the layer), 150 m, and 300 m. Often, 10 % of the depth is a rough first estimate for the thickness resolution of the LOTEM method. The calculated curves in figure 6.5 are well separated from each other so that we have a chance of resolving this parameter. However, it is not resolved uniquely, because a similar variation of the lower target layer could produce the same effect.

The next task in a feasibility study is to define the signal level which is important to know when predefining the field parameters. Figure 6.7 shows the same model variations as figure 6.6, but now the induced voltage in the receiver coil is displayed using typical field parameters. With the present system, the detection limit in the presence of moderate electromagnetic noise and assuming 0.5 hours averaging time at one station reaches down into the submicrovolt range (experience has shown that detectable signal limits lie between 1 and 0.001 μvolt). The signals in figure 6.7 are measurable up to about 0.5 seconds. The technically feasible, lower limit of the time window is at present a few tens of milliseconds. This results in a usable time window reaching from several milliseconds up to 0.5 seconds. Thus the variations shown in the previous examples lie within that measurable time window and can therefore be detected.

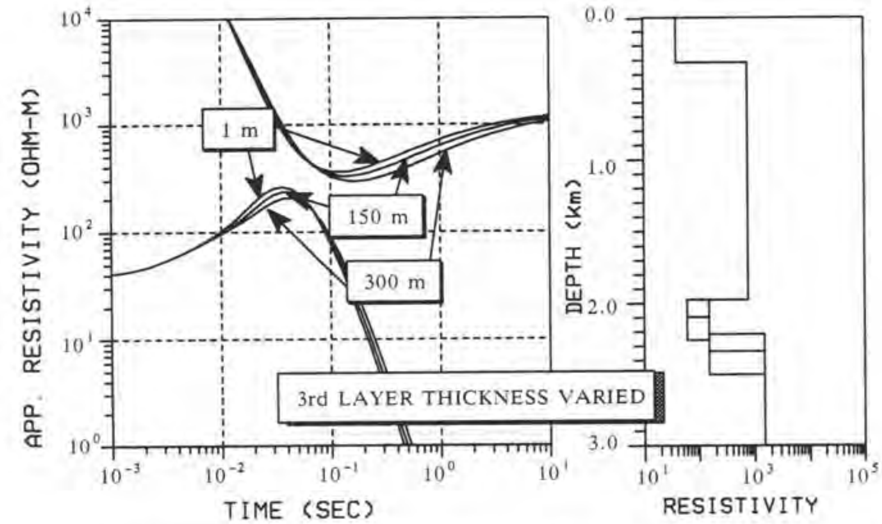

Fig. 6.5: Apparent resistivity curves for three different thicknesses of the third layer. The absence of this part of the target was simulated as an invisibly thin (1m) layer.

So far, the examples were calculated with a transmitter – receiver offset of 10 km. More model calculations are now required in order to check whether the offset could be optimized. For example, the same variations could be tried with an offset of 7 km and with 15 km. The points to observe when carrying out this fine tuning are:

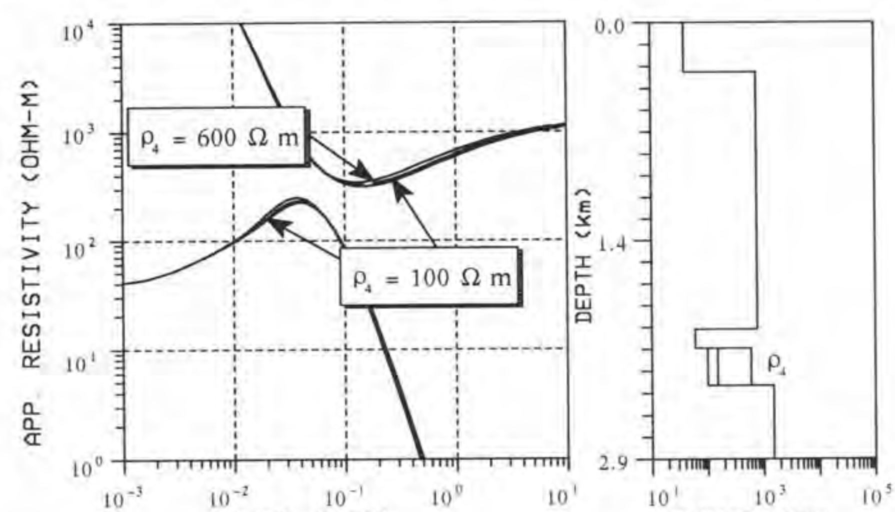

Fig. 6.6: Apparent resistivity curves for three different resistivities of the fourth layer.

- The signal level: it decreases rapidly with distance.
- The time window in which the variations are visible: it is shifted slightly with offset.
- The size of the variations: variations of deeper targets are generally stronger at larger offsets.

The previous examples introduced the well log reduction and the forward modeling for a *survey feasibility* study and for the *survey design*. The results from this preparation should be documented and summarized in a report well before the survey. The report is best structured chronologically, i.e. in the sequence in which the tasks were described in this chapter. At the end, there should be a table which summarizes the results of the forward modeling in a number of columns for each unit of the layered model:

- *LAYER NUMBER*.
- *RESISTIVITY (Ohm-m)*: include here only the variations, e.g. 100, 150, 600
- *THICKNESS (m)*: include here only the variations, e.g.1, 128, 300
- *GEOPHYSICAL APPEARANCE*: describe the effect of the variations on the simulated curves, e.g. strong influence from 0.02 s to 10 s, displacement of late time minimum.
- *GEOLOGICAL MEANING*: interpretation of the variation, e.g. changes in thickness of sandstone target.
- *TARGET RESOLUTION*: decision whether the parameter is resolvable or not, e.g. resolvable by late time asymptote.
- *FIGURE NUMBER*: cross reference to the figures (in the appendix of the report) which display the result of the variation, e.g. 3-4.

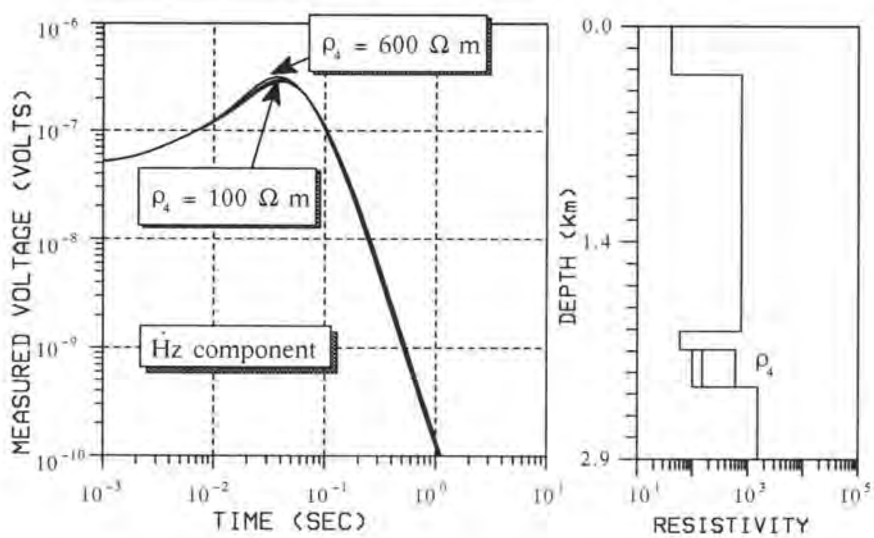

Fig. 6.7: Induced voltage in the receiver coil (signal level) for three different resistivities of the fourth layer.

With these data and the conditions in the target area, it is relatively easy to select an optimum survey layout. This should be done as final step to give input to the logistics operator for the survey design: optimum transmitter–receiver offset, optimum time window, required accuracy for the data. The latter always results in a tradeoff: the longer you stay at one receiver site the better your averaged signal becomes, but also the costs per station increase. The feasibility study can put limits on the required accuracy and therefore help in both, time–planning and in cost estimation.

You may refine the presurvey feasibility study even more, if you have more data available. If noise measurements from the survey area and the system response of your system exists, you may actually want to calculate synthetic, noisy, raw field data and simulate the whole interpretation process. The more time you spend on the feasibility study the more time you will save during the data acquisition and interpretation phase.

In the next section artificial noise is added to the data and the resolution is investigated under production conditions by looking at the inversion results.

RESOLVING A DEEP CARBONATE UNIT

A difficult target for EM techniques is the determination of resistivity and thickness of thick resistive units at a depth of 4 to 6 km. For production and exploration problems this is however very important because accurate porosity predictions can save money spent on dry wells. To simulate this situation we have selected a case history simulating an exploration situation in China (Baxian Depression). The objective of the feasibility study was to find the optimum survey strategy under the following conditions:

- The LOTEM measurements are carried out in a production mode along a profile.
- Two wells at either end of the profile and a good seismic section are available.
- The interpretation is restricted to one–dimensional modeling to maintain production and constrain the effort in interpretation.
- Archie's formula applies to the carbonates embedded in clastic sediments.

The color figures for this feasibility study are given in Appendix 7. Figure A.7.2 (top) shows an electrical section with three layers which has an additional fourth layer embedded between 4 and 6 km depth. The section without the additional layer represents the overall structure of the Baxian Depression according to Chen Leshou et al's (1988) interpretation of magnetotelluric data (table 6.3). The Baxian Depression is part of the Bohai Gulf Basin which has a great variety of different oil and gas pool systems related to structural and lithological parameters (figures 1.1–12 and 1.1–20 in Schlumberger, 1985). The additional layer in the model simulates the effect of a variable porosities in the carbonate sequence in the conductive environment of the Baxian area. The variations in electrical resistivity (compare table 6.3) are indicated by the colour coding in the figure. The basic model is displayed as the top frame in the figure.

Table 6.3: Resistivity models used for the resolution study.

Layer No.	LEFT MODEL Resistivity (Ohm–m)	Thickness (m)	3rd LAYER – VARIATIONS (Ohm–m)	RIGHT MODEL Resistivity (Ohm–m)	Thicknes (m)
1	21.0	770	–	21.0	770
2	4.4	3000	–	4.4	3000
3	4.4	2350	10, 15, 25, 50	100.0	2350
4	30.0	–	–	30.0	

Synthetic LOTEM data and synthetic magnetotelluric data were calculated for eleven receiver stations along a profile which crosses the region of resistivity variations of the simulated carbonate layer.

Artificial noise was added to the synthetic data in order to allow a realistic resolution study. The resulting synthetic data sets were then inverted in terms of layered models at each receiver station and the results assembled into an interpreted electrical section. Ideally, the original section should be recovered after this procedure.

Figure A.7.2 shows the results of interpreting single synthetic data sets without imposing any constraints on the curve fitting process. The first frame is the model section which was used to generate the synthetic data. The next frames show results of the procedure for LOTEM magnetic data, LOTEM electric data, and (in the bottom row) for magnetotelluric data. The curve fitting process for each of the three data types was initialized once with a model without the additional layer (left column) and once with a model with the additional layer (right column). This procedure simulates that the well log is input into the interpretation process. The interpretations show a strong dependence on the initialization of the curve fitting: the left column is quite different from the right column. Also, the resistivity variations in the original model could not be recovered; instead they appear as structural variations. None of these results would be acceptable in a real exploration environment.

The use of structural information such as an interpreted seismic section was simulated in figure A.7.3 by forcing the curve fitting process to leave the layer thicknesses fixed and vary only the resistivities of the units. Of the resulting interpretations the LOTEM electric fields and the magnetotelluric data can now reproduce the variations to some degree. However, the LOTEM electric fields do not give consistent information about the part of the section below the resistive unit. Also, all of the interpretations still depend on the starting model for the inversion.

Next, different data sets were combined using joint inversion. The result is displayed in figure A.7.4. The results in figure A.7.4 were obtained without *a priori* information about the structure. The results are equally unacceptable as for the independent inversions in figure A.7.2. Figure A.7.4 shows the joint inversion results when the structure is kept fixed. The first pair of frames shows the combination of LOTEM electric fields with LOTEM magnetic fields. The result has only marginally improved over the electric field interpretation in the previous figure. The center frames show the combination of LOTEM magnetic fields with magnetotelluric data. Since both data sets are more adapted to resolution of conductive targets, they are not successful in resolving the resistive target in this example. The last row shows the combination of LOTEM electric field data with magnetotelluric data. The result is an acceptable resolution of the resistive unit. The interpreted resistivity variations within that unit do not depend on the initialization of the curve fitting, and the part of the section below the resistive unit has little distortion left in it.

The resolution study with synthetic data and synthetic noise indicates that for the given exploration task the exploration strategy can be designed such that the resistive target layer is resolved. In the example the a variable resistive unit simulates a carbonate layer in the conductive sediments of the Baxian Depression. Its resistivity can be mapped when the structure is fixed on the basis of other information such as seismics, and when in addition a combination of the LOTEM electric field component with magnetotelluric data is measured and jointly interpreted.

HIGH RESOLUTION FEASIBILITY STUDY

A typical problem in exploration is the definition of porosity within resistive units at a depth between 1 to 2 km. Often these resistive units are either carbonates or diabase/dolerites. Following, a case history from Australia is shown where porosity variations are to be mapped within a dolerite unit. Above the dolerite are sandstones and silts of medium resistivity. A blocked well log is given in figure 6.8. The dolerite is clearly marked by a resistivity increase in the log at 1700 m depth.

The location of the well is marked in figure 6.9 which shows the two way traveltimes for the survey area. Also indicated in the section is the location of the seismic profile (see figure 6.10) used to derive the structure used for the forward modeling. In the seismic section, the dolerite is marked.

For the structure synthetic data were generated and 1% noise added. Porosity variations from of 5%, 10%, 20%, and 30% were modeled with the respective resistivity changes. This noise level is somewhat high for LOTEM data because the acquisition and processing eliminates most of the noise. However, during the forward model–

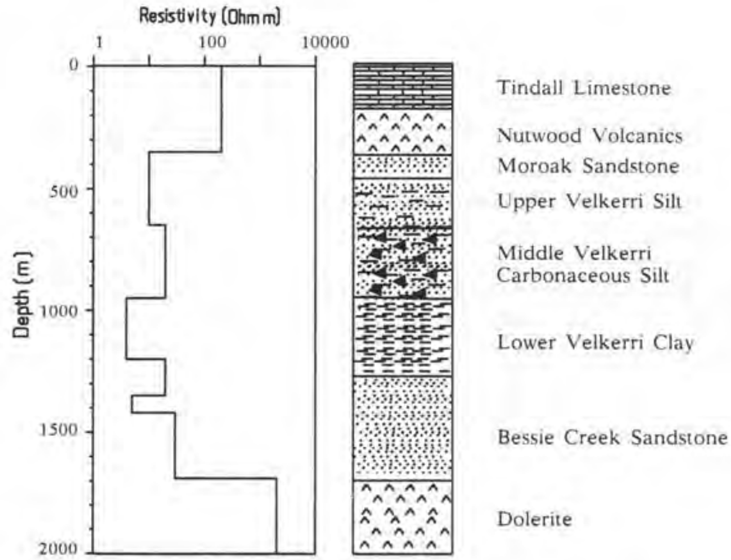

Fig. 6.8: Blocked electrical log for the well in the survey area in Australia.

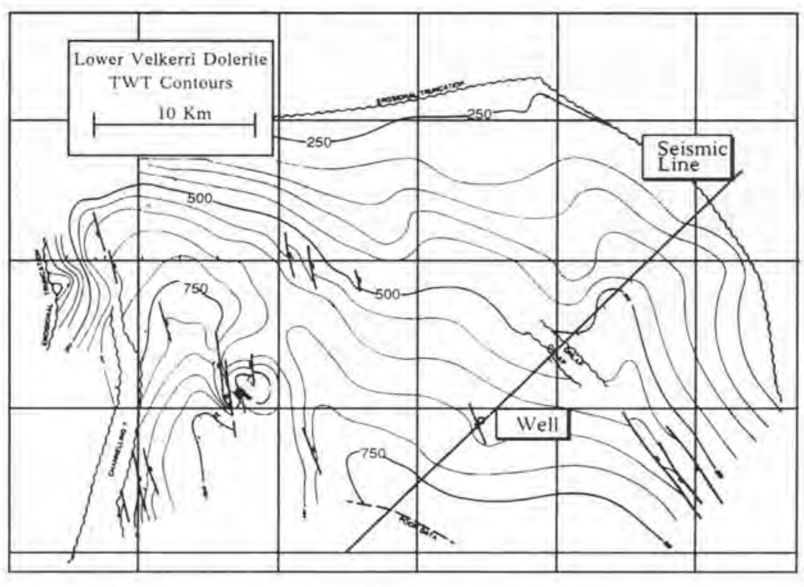

Fig. 6.9: Two way traveltime contours of the top of the dolerite unit.

ing process conservative estimates are usually used. The synthetic data were then interpreted and it was quickly concluded that the individual components would not yield the wanted results.

Thus, the feasibility study was continued using inversion as routine interpretation tool of the data. When keeping the structure fixed using the *a priori* information from the seismic in figure 6.10 the result in figure A.7.5 (Appendix 7 – color figures) was obtained. At the top of the figure the electrical models used to generate the synthetic data is shown. Below, are the inversion results are color coded. Although one can already see some resemblance with the original model the deviation on the edges of the profile are too large. This indicates that more parameters must be known as *a priori* information.

Possible additional techniques include shallow TEM soundings and magnetotellurics. The shallow TEM soundings would give a reliable estimate for the top layer resistivity while the MT would give a reliable estimate of the basement. Using these estimates one can keep the top and bottom resistivities fixed which was done for the computations in figure A.7.5 (bottom frame). Now the inversion result shows a close resemblance of the model.

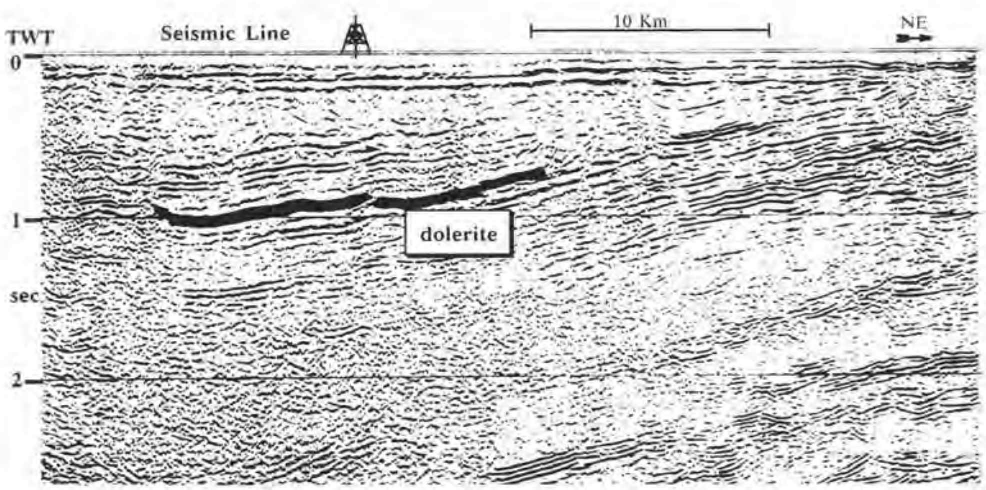

Fig. 6.10: Seismic section indicated in figure 6.9. the dark area marks the dolerite unit.

From these results one would suggest adding along a LOTEM profile some sparse TEM and MT soundings to constrain the top and bottom resistivities and obtain the maximum resolution for the target layer. From the previous study we know that only when a limited number of layers of sufficient thickness exists we can resolve deep target without high resolution shallow information. The study for an area in Australia suggests that one must be very careful when the section is only moderately more complicated. not only does the approach for the interpretation change but one also needs additional measurements. It is very important that this is known before the survey is planned and not found out during the interpretation phase when it is often too late.

FEASIBILITY STUDY OF A TWO-DIMENSIONAL STRUCTURE

The next feasibility study considers a more complex possible application of LOTEM. The exploration problem is from an area in Japan. The objective was to map a swarm of conductive dikes at a depth of approximately 500 m. The structure is considered two-dimensional for a practical purposes. Around the conductive dikes is medium to high resistive material separated by fault zones. the entire structure is embedded in high resistive background material. the situation could simulate a variety of situation encountered in mineral exploration but also in geothermal exploration.

A two-dimensional model as constructed and the SLDM program (Druskin and Knizhnerman, 1988) (see chapter 4) was applied in a 2-D mode to calculate the response of a LOTEM setup. The model is shown in figure 6.11 and the plan view in figure 6.12. In figure 6.11 are also the receiver location above the model and several selected characteristic transients displayed in the top portion of the figure. The corresponding profile location is shown in figure 6.12. The electric field stations are coincident withe locations where the time derivative of the magnetic field is calculated (recorded). The surface projection of the 1 Ohm-m conductive dikes is also shown in figure 6.12. The anomalous body extends further to the sparsely sampled parts on the right of the profile. First, the electric field transients are shown and below the apparent resistivities (using the early time apparent resistivity formulation) of the time derivative of the magnetic field. The transient response at the far end of the profile show no anomalous behavior and are essential similar to the 1-D response. When approaching, one can notice anomalous behavior going over to sign reversals near the edge of the structure. Stations 61 is the last non-reversed transient on the profile. In the corresponding electric field measurement (station 15) at the same surface location one can already see some change in signal behavior when comparing it with the signal at station 01. At station 62 the magnetic field transient contains a sign reversal (thus displayed as squares). In the electric field this reversal can only be observed one station further on the profile (station 17). At the magnetic field station 69 at the far end of the profile a sign reversal in the signal is observed again beyond the far edge of the anomaly. The corresponding electric field response is now shifted in the opposite direction.

If we consider that the objective is definition if LOTEM is applicable to this exploration target, we have to give a more modified answer as for the above feasibility studies. Considering that the synthetic transients exhibit reversals, it is clear that one-dimensional interpretation will not give the wanted result. This means that at least 2-D and probably even 3-D interpretation must be used. For 3-D interpretation the key is

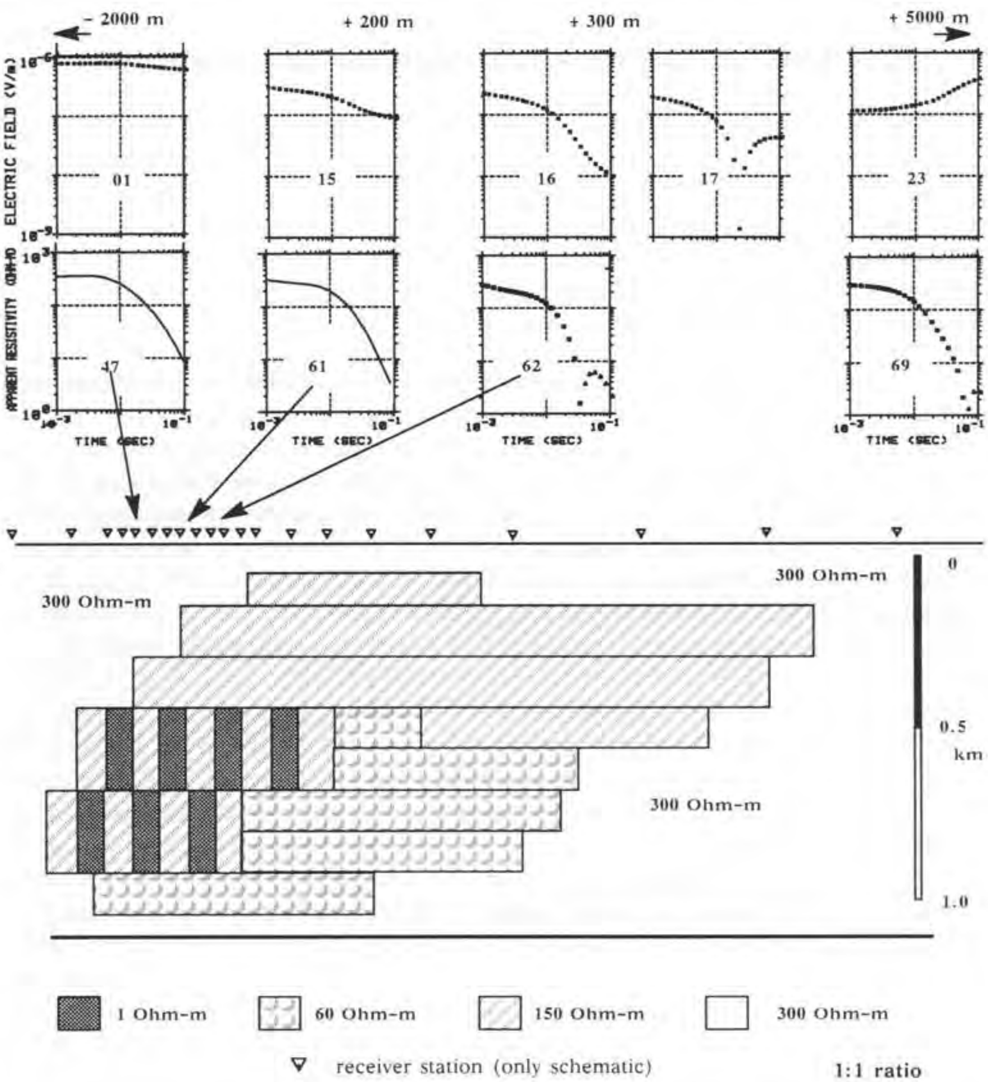

Fig. 6.11: Two-dimensional section view of the model used for the computation of the transient responses shown in the upper half of the figure.

to find a good starting model since 3-D modeling takes significant computational effort. This requires that the data are measured on parallel profiles or even better on a grid. The electric fields should be measured because the time difference between the occurrence of the first reversal in the electric and magnetic field data can give an additional indication on where the edge of the body is located. The operational mode in which the data should be collected is preferably a profiling mode similar to what is routinely used by the mining industry.

For this particular two-dimensional problem we can summarized results from the feasibility study:

- LOTEM electric and magnetic field should be measured at the same surface location to be able to locate the edge of the anomalous zone.
- The data should be collected at least on parallel profiles or even better on a grid to allow the best estimate of the starting model for the 2-D or 3-D modeling.
- The data should be initially displayed in a profiling sense and soundings on at selected parts of the profile where the 3-D anomaly is significantly weaker than the one-dimensional response.

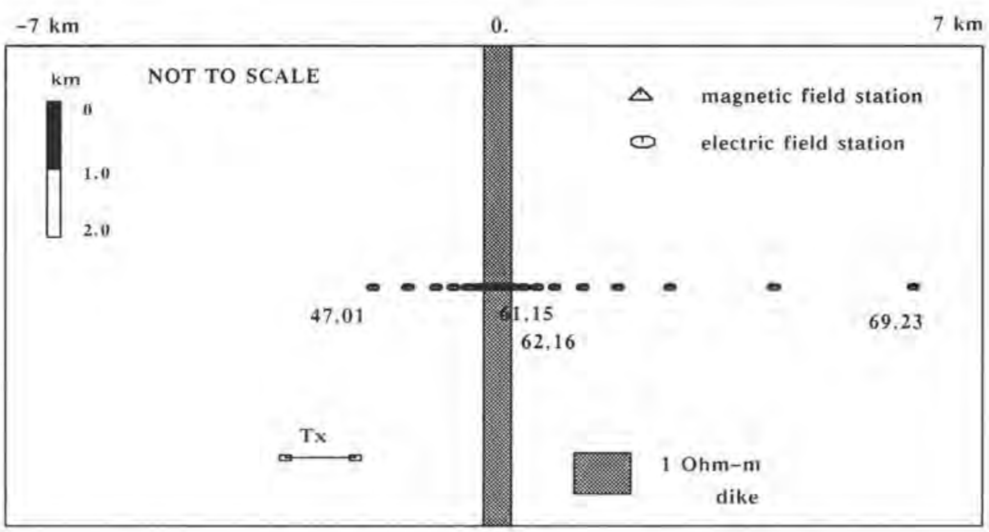

Fig. 6.12: Plan view of the two-dimensional section displayed figure 6.11 and the location of the profile of which selected data sets are shown.

SUMMARY CHAPTER 6

Before carrying out a field survey, the feasibility of the technique for the problem on hand must be investigated. In order to obtain a realistic estimate of the performance of the LOTEM technique in a new environment, it is important to consider all available information concerning the resistivity structure and the general geology is obtained.

The most common way of deriving a reasonable model for the LOTEM method is the layer equivalencing applied to well log (induction log) data. The log is blocked such that a minimum structure is obtained, but the general trend of the well log is still preserved. When further reduction in the number of layers is being made, one must make sure that the resulting responses in the electromagnetic field are identical.

Once the optimum model is found and the target parameter variations are known, the responses can be calculated and an optimum offset determined. For this optimum offset one can then calculate the actual received voltages to confirm that the acquisition system on hand can resolve the parameters.

During all phases of the modeling and feasibility study one must make sure that the direct relation to the geology is maintained. Often the target has to be lumped together with overlying or underlying strata. In that case, one might have to resort to inversions and analysis of the resolution statistics for an optimum survey feasibility study.

For an exploration situation in the Baxian Depression, China a feasibility study was carried out. It showed that the optimum survey strategy should include LOTEM and magnetotellurics and should use for the interpretation the structure from seismics. This combination is capable of mapping in a production operation bulk porosity variation at a depth of approximately 4 to 6 km.

In Australia, the objective of the forward modeling was to define which methods and approaches would be required to map porosity variations within a dolerite unit (production application). the forward modeling shows that for near surface control one needs shallow TEM, for the intermediate depth LOTEM, and for the greatest depth MT. Only the combination of all three techniques in combination with *a priori* information from seismics (structure) will give the required high resolution.

In Japan, are complicated two-dimensional anomaly had to be investigated. From 2-D modeling it is clear that sounding interpretation is not applicable in this case. However, a combination of LOTEM electric and magnetic field data collected on a densely spaced grid can delineate the zone of interest and allow the derivation of a model for the exploration target.

PROBLEMS CHAPTER 6

1. Conduct a survey feasibility study for a typical European situation (strong cultural noise).This should include:

   - Well log reduction and deviation of the more reasonable geoelectric model, which shows the minimum structure but honors the geology.
   - First reduce the well log to some number of layers between 6 and 10 and then cross check all further reductions to deep layers graphically. Stop your reduction when either geology contradicts to the layer boundaries or the deviation between the consecutive reductions becomes too large.

The data picked from the well log is (first depth then resitivities):

Problem 1 log
0,80.
725,80.
770,80.
810,6.
860,40.
1140,11.
1220,100.
1450,11.
1680,40.
1830,6.
1900,60.
1960,8.
2050,35.
2080,6.5
2100,45.
2200,6.
2250,30.
2800,4.
3000,4.

You also know from the borehole geology:

Table 6.4: Data of a blocked electrical log maintaining the lithological boundaries.

Depth	Approximate Resistivity	Lithology
0 – 700 m	medium high	limestone
700 – 2300 m	medium conductive 10 – 15 km	Mesozoic sediments sediments
2300 – 3000 m	conductive 5km	sediments
3000 – 4500 m	medium conductive	sediments
4500 m	resistive	basement

The target is the conductive sedimentary unit between 2300 and 3000 m!

- ❍ Simulate resistivity variation for all units with emphasis on the target layer. Make sure you determine the optimum offset for the survey.
- ❍ Which component is more suitable, the vertical magnetic field or the electric field components?
- ❍ Give optimum survey parameters.
- ❍ Would you include another geophysical method? If so, why?

2. *Volcanic cover:*
A typical exploration situation is the definition of the thickness of sediments under volcanic cover (USA, India, Brazil, FRG etc.). Common resistivity values for the top volcanic layer is just below 100 Ωm (70 – 90 Ωm). These thicknesses range between 200 to 1500 m. The thicknesses of these sediments below is between 500 to 2500 m. They are underlain by resistive basement material.
   - ❍ Define the optimum offset using MODALL of a LOTEM setup for thickness variations of the sediments of 800 to 2000 m.
   - ❍ What source currents and receiver moments do you need to have the target response above 1 microvolt?

3. *Deep crustal applications:*
You have been asked to assess the applicability of LOTEM to deep crustal problems. You know that a low velocity zone is expected from 7 km (uncertain) to 12 km. The top layer (2 – 3 km) is made up of 150 Ωm material followed by 8000 – 20000 Ωm crystaline rock.
   - ❍ Derive the possible model.
   - ❍ Define possible variations of the parameters.
   - ❍ What is the optimum offset?
   - ❍ What noise level can you tolerate to resolve your target?

4. *Overthrust*:
An overthrust varies in thickness from 20 m to 2000 m over a distance of 25 km. Its resistivity is 150 Ωm. Below sediments (3 – 8 Ωm) with a maximum thickness of 2500 m are expected. Please design all survey parameters.

5. *Carbonates at depth:*
At 2 km depth is a carbonate unit of 200–700 m thickness. The overlying strata have a resistivity of 3 – 8 Ωm. The sediments below (to 5 km depth) about 15 Ωm. Design a survey which allows you to map porosity variations within the carbonates of 5, 10, 30, 50%.

6. You are asked to map a 20 m thick resistive (200 Ωm) unit within conductive sediments (5 Ωm) The resistive unit is at 2000 m depth. What would you do if you have to be successful?

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