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EVALUATION OF LOW RESISTIVITY LOW CONTRAST RESERVOIR

MUHAMMAD AMIN NIZAR BIN

CHE ABD RAZAK

PETROLEUM ENGINEERING

UNIVERSITI TEKNOLOGI PETRONAS

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Muhammad Amin Nizar Bin Che Abd Razak

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Dissertation submitted in partial fulfillment of the requirements for the
Bachelor of Engineering (Hons)
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Universiti Teknologi PETRONAS
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Petroleum Engineering Programme
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Approved by,

____

(Mr. Elias B Abllah)
Supervisor

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
January 2006

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

MUHAMMAD AMIN NIZAR BIN CHE ABD RAZAK

ABSTRACT

The combination of conventional logs such as density, neutron and resistivity logs is proven to be very effective in the evaluation of normal reservoirs. An accurate determination of the petrophysical parameters with the conventional logs for low resistivity reservoirs is very difficult. The problem of these reservoirs is that conventional logging interpretation shows water zones, but water free hydrocarbon would be produced. In the case of low resistivity contrast reservoirs it is very hard to determine water hydrocarbon contact with resistivity logs. The project will involve on remodeling of low contrast reservoir by represent it by saturated core sample. The resistivity of the core sample saturated with different fluids will be compared to see any effect of low contrast reservoir. Nuclear Magnetic Resonance (NMR) logging method would be also suggested as an alternative to the conventional logging method since the method shown the capability to resolve the problem with low contrast reservoir without the needs of very thorough interpretation. The NMR logging method will make the process of evaluating the LRLC reservoir easier and more accurate.

ACKNOWLEDGEMENT

Alhamdulillah, praise the Almighty for his bless and his permission, I managed to complete this final year project entitled Evaluation of Low Resistivity Low Contrast Reservoir. I would like to express my deepest appreciations to the Geosciences and Petroleum Engineering Department, Universiti Teknologi PETRONAS (UTP) which is led by Assoc. Prof. Dr. Ismail Bin Mohd Saaid (Head, Petroleum Engineering Department) for providing me the petroleum engineering related information and facilities in accomplishing my final year project. My greatest gratitude goes to my supervisor, Mr. Elias B Abllah (Lecturer, Petroleum Engineering Department) for guiding and assisting me throughout the year. Being with him had given me valuable experiences which I believe will be helpful in the future. I would also like to thank Dr. Hilfan Khairy (Lecturer, Geosciences Department) and Mr. Shahrir (PhD. Student) for their assistant during my Autolab session. My outmost heartfelt appreciation goes to my parents for their support and prayers. Last but not least, I would like to thank all lecturers and staffs of Geoscience and Petroleum Engineering Department, my colleagues, classmates, housemates and all UTP students who have been supporting me throughout this final year project period.

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CHAPTER 1 INTRODUCTION

In unfractured reservoirs, Low Resistivity Low Contrast (LRLC) pay zones are usually associated with one or more of the following: laminated reservoir/non-reservoir sequences, formations with multimodal pore-size characteristics, sediments with anomalously high surface area, and reservoir components that extend beyond the range of applicability of interpretative algorithms. For the low resistivity cases, hydrocarbons have been produced with little or no water cut in the presence of high interpreted water saturations, in many different parts of the world. While for the low resistivity contrast cases, the resistivity of the fluids in the formation are not in so much difference, therefore water resistivity is often mistaken as oil resistivity. The formation when completed will produce water instead of oil. Therefore it is important to have a generalized facility for recognizing LRLC pay as early as possible in the life of a prospect.

LRLC pay is not recognizable through conventional log analysis. Historically, therefore, LRLC pay has always not been targeted for primary completions, being discovered through core and pressure analysis as late as a higher-risk, third completion stage. Much of the locally applicable, empirical rationale behind the initial overlooking and the subsequent discovering of low-resistivity pay have been lost to the industry with the passage of time. However, the parameter cut-off culture virtually guaranteed that all admitted pay intervals would show fairly consistent reservoir properties with LRLC pay going undetected, at least initially.

This project will look into more depth to the problems faced by low contrast reservoir. The resistivities of cores saturated with distill water, crude oil and saline water will be determined and compared. This project also will recognize Nuclear Magnetic Resonance logging method as one of the solution for LRLC reservoir. The current conventional method had not been able to interpret this type of formation perfectly and often the result does not represent the real formation properties. The problem further caused the misinterpretation of formation fluids. The real water saturation and oil saturation cannot be determined from the conventional logging method. The problem is caused due to resistivity, where the resistivity logging tools are not able to measure the true resistivity content of the formation due to the low resistivity and low resistivity contrast effect. Since resistivity is the main problem here, then the idea is rather than measuring resistivity instead formation magnetic properties is measured to identify the formation fluids.

1.1 Background Study

LRLC reservoir had been commonly considered wet, misunderstood for shale and completely overlooked due to logging tool resolution limitations. Although the term low resistivity and low contrast often grouped together but there is a difference between those two terms. Low resistivity pay is generally characterized by pay zones that cause deep resistivity log curves to read around 0.5 to 5 ohm-meter. This is often attributed to a combination of shale content, mineralogy, microporosity and bed thickness. On the other hand, Low contrast pay implies a lack of resistivity contrast between pay sands and adjacent shales or wet zones. This problem is most commonly seen when the resistivity tool encounters a zone that contains fresh water or waters of low salinity. As salinity decreases, the electrical pathway through a body of water becomes weaker and more dispersed, thus causing the water to become less conductive or in other words is becoming more resistive. Therefore, while the resistivity of the pay zone may not be low, the resistivity of the water leg is high enough to make it difficult to distinguish between pay and wet zones. (Kulha, 2004)
(Stolper, 1994) (Passey, Dahlberg, Sullivan, Yin, Brackett, & Guzman-Garcia, 2006)

Geological causes of LRLC pay include: laminated clean sands with shales; silts or shaly sands; clay-coated sands; glauconitic sands; sands with interstitial dispersed clay; sands with disseminated pyrite or other conductive minerals; clay-lined burrows; clay clasts; altered volcanic/feldspathic framework grains; very fine-grained sands; microporosity; or sands with very saline formation water. These are the geological occurrences that results from the combination of the factors below:

1. Bed Thickness: some pay zones are simply too thin to be resolved by the logging tool.
2. Grain Size: very fine grain size can lead to high irreducible water saturation.

3. Mineralogy: conductive minerals (such as pyrite, glauconite, hematite, or graphite) or rock fragments can have a pronounced effect on resistivity response.
4. Structural Dip: dipping beds produce significant excursions on the resistivity log when orientation between the tool and the bed deviates from normal.
5. Clay Distribution: classified as either dispersed, structural, or laminated - all capable of holding bound water.
6. Water Salinity: high salinity interstitial water causes low resistivity within the pay zone, while low salinity water can cause low contrast pays.

LRLC depositional systems include deep-water fans, with levee-channel complexes, delta front and toe deposits, shingle turbidites and alluvial and deltaic channel fills. The conventional logging tools lack of resolution had caused the formation or sands to be below the tools cutoff value and while it is not being identified as shale, this formation is categorized as LRLC reservoir. (Hamada, Al-Blehed, & Al-Awad, Determining Petrophysical Properties of Low Resistivity Reservoirs, 1999)

Nuclear Magnetic Resonance (NMR) is one of the logging tools used in the petroleum industry. The principle for NMR is it evolves around the concept of magnetic nuclei (^{1}H or ^{13}C) in a magnetic field to absorb and reemits electromagnetic radiation. Some of the advantages of using NMR are its ability to map or detect the fluid content and not be influence by rock matrix. (Hamada, SPE, Al-Blehed, & Al-Awad, 2000) (Coates, Xiao, & Prammer, 1999)

NMR has been develop and had been in the industry for about 60 years. It was first introduced in the industry in 1950s. If it is compared with the other formation evaluation tools, then it can be considered new. When it was first studied the researchers conduct those early attempts by using the earth's magnetic field, which is rather weak, so they were not wildly successful. In 1961, they made the first attempt for NMR commercialization. Then in 1960s, Schlumberger made their first step to acquire and develop NMR technology. The company licensed the tool that had been developed by Chevron. With the technology in their hands, Schlumberger further developed and created the next generation NMR tools during 1970s and 1980s. It is not until 1990s that mark the rebirth and new potential for NMR. In 1990s, NMR had been developed to use new technology at that time which was using pulsed acquisition to evaluate formation. In the past, the tool was very slow and this lead to higher time and cost consumption but with the new technology, the tool became reasonably faster. It all start with the success of using the new generation of NMR for evaluating East Texas and Gulf Coast formation which was known that it would be difficult to evaluate using conventional formation evaluation methods. During that decade also, NUMAR a Halliburton company developed a mandrill type tool which provide effective porosity measurement. The tool was still considered slow although many developments were made. The operating speed for the tool at that time is about one foot per minute. Then in 1995, newer generation of NMR had been developed, using multiple frequencies to do formation evaluation. The tool reached an operating speed of about 5 feet per minute and allowed for total porosity measurement instead of only effective porosity measurement. Currently NMR had been develop to reach higher operating speed while keeping the data quality to be as high as possible. Further research had been done to further increase the speed of other logging tools and projected to be included in the Logging While Drilling (LWD) tools.

Today there are two NMR tool designs commercially available. Even though the tools are fundamentally different, both can handle most formation evaluation problems, although they may require different interpretation techniques, or in some cases need to be complemented with conventional logs. The magnetic resonance imaging log, or MRIL, is a mandrel-type tool and was developed by NUMAR was commercially available in 1991. Then they further develop C series in 1994, the C-TP series in 1996 and the MRIL-Prime tool in 1999 followed by the original NUMAR B series. Each design provided major improvements in logging speed and acquisition capabilities. The Prime tool's logging speed is about 10-times faster than the original B series tool, and it simultaneously gathers several data sets with better repeatability. The combinable magnetic resonance tool, or CMR, is a pad mounted tool designed by Schlumberger that was offered commercially in 1992. In 1996 the tool was upgraded to the CMR-200, a total porosity version with improved signal to noise characteristics. Currently Schlumberger is introducing its CMR Plus tool, a major design modification that reportedly offers faster logging speeds compared to the standard CMR.

In the industry, one of the indicators to differentiate between oil zone and water zone is by using resistivity logs. Resistivity log is included in the conventional logging tools package. All resistivity logs respond to real rocks and all petrophysical analysis procedures to determine water saturation, and hence hydrocarbon saturation, are based on the Archie's Law. Most sedimentary rock minerals are very poor conductors so most of the current flows through the water in the pores and not through the rock material. Therefore, the manner in which currents flow through water must be examined. This is basically the concept for resistivity logging.

In the reservoir, water will mostly be saline and rich with minerals. Thus it's very much is a conductive region. On the other hand, pure water is a very poor conductor but if salt is added to water, the solution becomes more conductive. Current is conducted through water by ions formed from the salt in solution in the water. The more ions present in the solution, the more conductive the solution will be. Since most natural waters in rocks contain salts of various kinds, the majority of natural waters are conductive. (Crain)

1.2 Problem Statement

There are lots of problems associated with LRLC. Low resistivity, low contrast pay intervals had been recognize and seen through many logs in the past. Although many had encounter this formation but they often are not being developed and their economic significance has historically been overlooked. In the past, this formation was either assumed to be tight or water-bearing based on conventional logging method. The low resistivity, low contrast pay zones are difficult to interpret with conventional logging method which is by using resistivity log. This is due to the little resistivity difference and contrast between water bearing reservoir and oil bearing reservoir. The formation would often be evaluated to have very high water saturation but water-free hydrocarbon would be produced.

The problems with Low Resistivity reservoirs is firstly the resistivity data interpretation of the formation evaluation shows high water saturation but in reality even water free hydrocarbon can be produced from the well. This is usually caused by microporosity. Secondly, the problem with low resistivity reservoirs is the calculated water saturation is higher than the true water saturation. This can be caused by presence of conductive minerals in the formation which disturb the conventional logging tool measurement.

On the other hand, the problem with Low Resistivity Contrast reservoir is that there is a small resistivity difference between water bearing zone and oil bearing zone. This often led to wrong interpretation of the formation. Sometimes, the fluid is interpreted as oil but when produced, only water come out and vice versa.

1.3 Objective

The first objective for this project is to evaluate best representative of low contrast reservoir formation using saturated cores measured with resistivity machine. This will in turn see whether is it true that core saturated with distill water and core saturated with crude oil give almost similar resistivity readings.

The second objective is to study on NMR properties that make it the best alternative to evaluate LRLC reservoir which will in turn help to improve the result of conventional logging tools data.

1.4 Scope of Study

This study will put more focus on problems caused by Low Contrast reservoir. Common problems faced by engineers when they encounter low resistivity contrast will be studied. Then, laboratory testing and measurement method will be used to identify resistivity for hydrocarbon and water at core sample level. The whole operation will assume the core sample chosen to represent the reservoir. The resistivity for water and hydrocarbon will be tested using conventional formation evaluation method to be set as the base data. The result will be also used to evaluate the fluid content of the core. NMR machine will be used to create T2 readings for various fluids and see whether it can differentiate between the fluids.

CHAPTER 2 LITERATURE REVIEW

G.M. Hamada, 2000, says that the combination of conventional logs such as density, neutron and resistivity logs is proven to be very effective in the evaluation of normal reservoirs but for low resistivity reservoirs, however, an accurate determination of the petrophysical parameters with the conventional log reservoirs is very difficult. One of the causes is due to the low resistivity contrast between water bearing reservoir and oil bearing reservoir.

2.1 NMR logging tools principles and application

2.1.1 Fluid Quantity

NMR tool can directly measure the density of hydrogen nuclei in reservoir fluids. This is because the density of hydrogen nuclei present in water is known so the data from NMR tool can be directly converted to an apparent water-filled porosity. This conversion can be done without any knowledge of the minerals that make up the solid fraction of the rock, and without any concern about trace elements in the fluids that can perturb neutron porosity measurements. (Coates, Xiao, & Prammer, 1999)

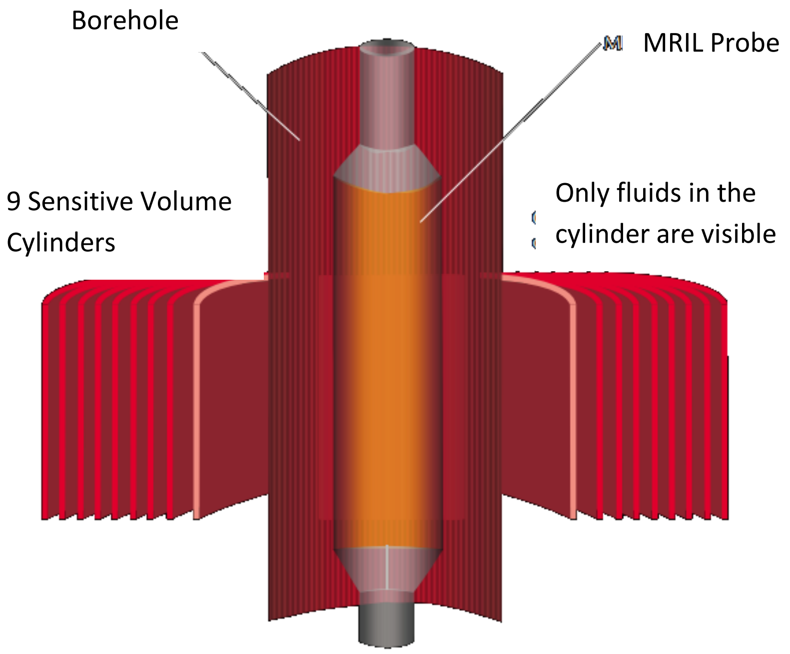


Figure 1 - MRIL Prime Tool

2.1.2 Fluid Properties

Medical MRI relies on the ability to link specific medical conditions or organs in the body to different NMR behavior. A similar approach can be used with NMR tools to study fluids in a thin zone a few inches from the borehole wall. NMR tools can determine the presence and quantities of different fluids (water, oil, and gas), as well as some of the specific properties of the fluids (for example, viscosity). Both medical-MRI devices and NMR tools can be run with specific pulse-sequence settings, or "activations," that enhance their ability to detect particular fluid conditions. (Coates, Xiao, & Prammer, 1999)

2.1.3 Pore Size and Porosity

The NMR behavior of a fluid in the pore space of a reservoir rock is different from the NMR behavior of the fluid in bulk form. Simpler methods can be used to extract enough pore-size information from NMR data to greatly improve the estimation of such key petrophysical properties as permeability and the volume of capillary-bound water. Earlier generations of NMR logging tools were unable to see water in these micro pores, and because this water was associated most often with clays, the porosity measured by these earlier tools was often characterized as being an "effective porosity." Modern NMR logging tools can see essentially all the fluids in the pore space, and the porosity measurement made by these tools is thus characterized as being a "total-porosity" measurement. Pore-size information supplied by the modern tools is used to calculate an effective porosity that mimics the porosity measured by the older NMR tools. In addition, one of the key features of the MRIL design philosophy is that the NMR measurements of the formation made when the MRIL tool is in the wellbore can be duplicated in the laboratory by NMR measurements made on rock cores recovered from the formation. This ability to make repeatable measurements under very different conditions is what makes it possible for researchers to calibrate the NMR measurements to the petrophysical properties of interest (such as pore size) to the end user of MRIL data. The common volumetric model used in the comparison consists of a matrix component and a pore-fluid component. The matrix component is composed of clay minerals and non-clay minerals, and the pore-fluid component is composed of water and hydrocarbons. (Coates, Xiao, & Prammer, 1999)

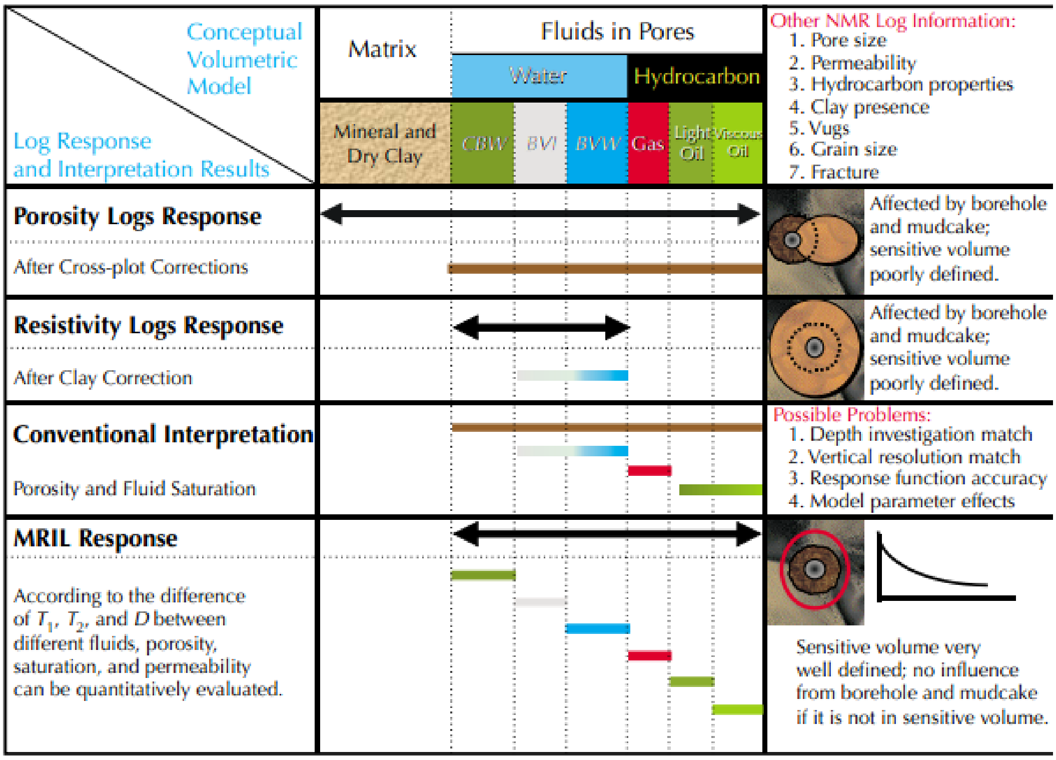


Figure 2 - Comparison of NMR responses with those of conventional logging tools

Conceptually, the pore fluids can be more finely divided into clay-bound water, capillary-bound water, movable water, gas, light oil, medium-viscosity oil, and heavy oil. Although conventional porosity tools, such as neutron, density, and sonic, exhibit a bulk response to all components of the volumetric model, they are more sensitive to matrix materials than to pore fluids. Furthermore, the responses of these tools are highly affected by the borehole and mudcake, and the sensitive volumes of these tools are not as well defined as that of the MRIL tool. Resistivity tools, such as induction and laterolog, respond to conductive fluids such as clay-bound water, capillary-bound water, and movable water. Based on the conductivity contrast between (1) clay-bound water and (2) capillary-bound and movable water, the dual-water and Waxman-Smits models were developed for better estimation of water saturation. Even with these models, recognition of pay zones is still difficult because no conductivity contrast exists between capillary-bound water and movable water. As with the conventional porosity tools, resistivity tools are very sensitive to the borehole and mudcake, and their sensitive volumes are poorly defined. Conventional log interpretation uses environmentally corrected porosity and resistivity logs to determine formation porosity and water saturation. It will be tough to distinguish light oil, medium-viscosity oil, and heavy oil.

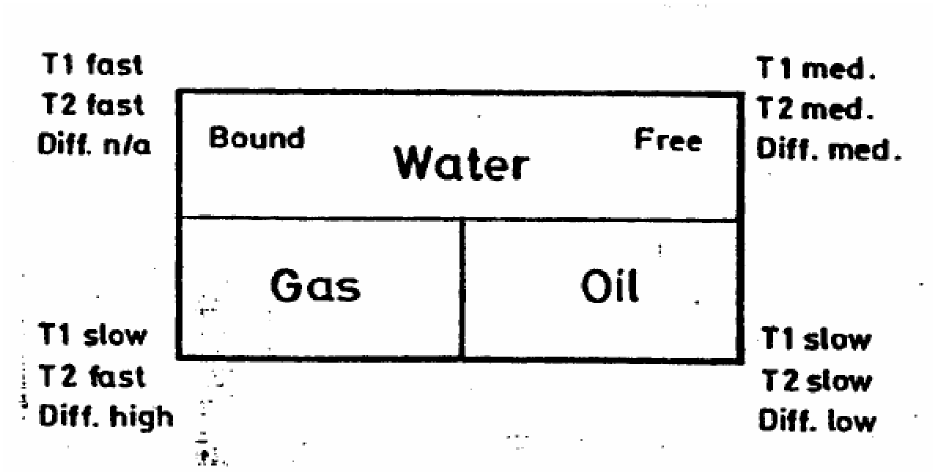


Figure 3 - Fluid Identification

As indicated in Figure 2, NMR porosity is essentially matrix-independent that is, NMR tools are sensitive only to pore fluids. The difference in various NMR properties such as relaxation times (T1 and T2) and diffusivity (D) are among various fluids makes it possible to distinguish (in the zone of investigation) among bound water, movable water, gas, light oil, medium-viscosity oil, and heavy oil. A cut off value will be set by each of the company standard code to categorize the type of fluid. There will be cut off value for T1, T2 and diffusivity. (Coates, Xiao, & Prammer, 1999)

2.2 Diffusion

Thermally activated random (Brownian) motion of molecules in a fluid. Diffusion in a gradient magnetic field causes a reduction in the apparent T_2 measured by the CPMG process.

2.3 Effective porosity

The total porosity less the porosity filled with clay mineral bound water.

2.4 FFI (Free Fluid Index)

The pore space occupied by fluid that is free to flow from the formation.

2.5 Longitudinal Relaxation Time, T_1

The time constant associated with longitudinal, or spin-lattice, relaxation required for the nuclei to align with the static magnetic field.

2.6 Transverse Relaxation Time, T_2

The time constant reflecting the rate of transverse energy loss, through spin-spin relaxation, that was created by a perturbing radio frequency pulse.

2.7 Time Echoes, TE

The time between echoes of the resonance implied to the formation.

2.8 Total porosity

The non-solids percentage of the rock bulk volume.

2.9 Wait Time, T_W

The time needed to allow a specific number of nuclei to recover their realized state. This parameter is dependent upon the T_1 relaxation of the involved pore sizes and their fluids.

G.M. Hamada et al presented three examples of low resistivity reservoirs. Analysis of NMR data of low resistivity zones has helped to identify the producibility of these reservoirs zones, to determine lithology independent porosity and to distinguish between bound and free water. In case of low contrast resistivity reservoirs where there was little resistivity contrast between water bearing formation and oil-bearing formation; NMR has been able to identify the fluid nature of the two formations and then the height of the oil column. This was based mainly on high contrast of NMR relaxation parameters.

In formation evaluation, resistivity logs are the main pay zones identifiers because of resistivity contrast between oil zone and water zone. If, however, a pay zone exhibits low resistivity, these logs become incapable to identify the producing zones and also to indicate water mobility. Because of this limitation, many potentially productive zones with high irreducible water saturation are overlooked. The problem of low resistivity reservoir usually is not one of being able to determine the presence of hydrocarbons. Generally, standard log analysis will identify the hydrocarbon bearing zones. The problem is to be able to predict that little or no water will be produced even though log analyses indicate that the formation has high water saturation. The most promising candidate to solve this problem is the nuclear magnetic resonance log. NMR log can identify water free production zones, correlate bound fluid volume with clay minerals inclusions in the reservoir and identify hydrocarbon type.

Dr. Lutz Riepe et al had conducted an integrated petrophysical evaluation for LRLC pays in clastic reservoir in South East Asia. They mainly try to tackle and improved the concepts and developed workflows for the identification and evaluation of productive hydrocarbon bearing LRLC zones. They manage to create two workflows which are first for Special Core Analysis (SCAL) and second for Resistivity log and NMR logs.

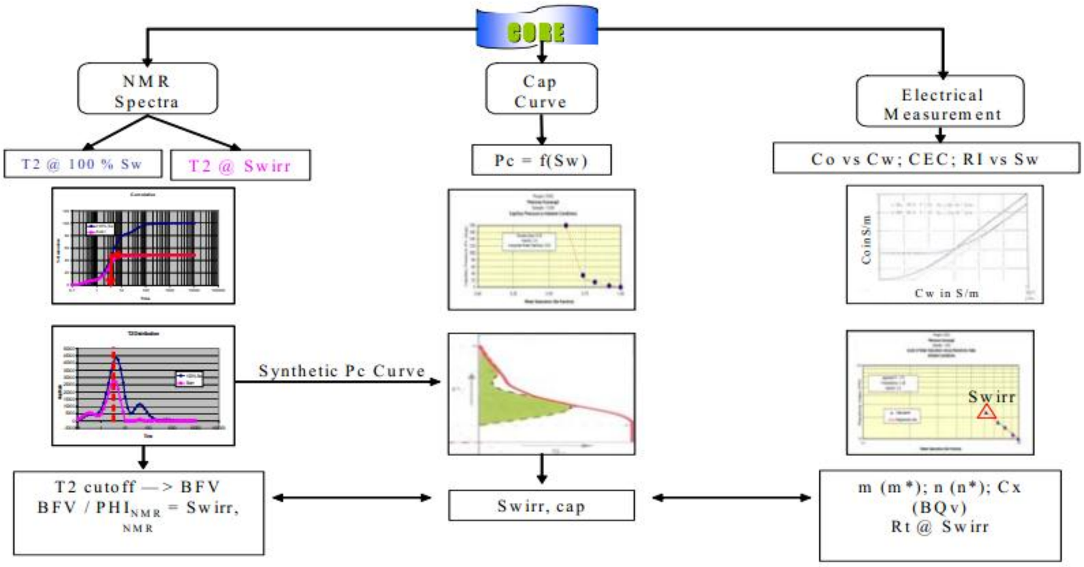


Figure 4 - Workflow for the evaluation and reconciliation of irreducible water saturation Swirr from Special Core Analysis

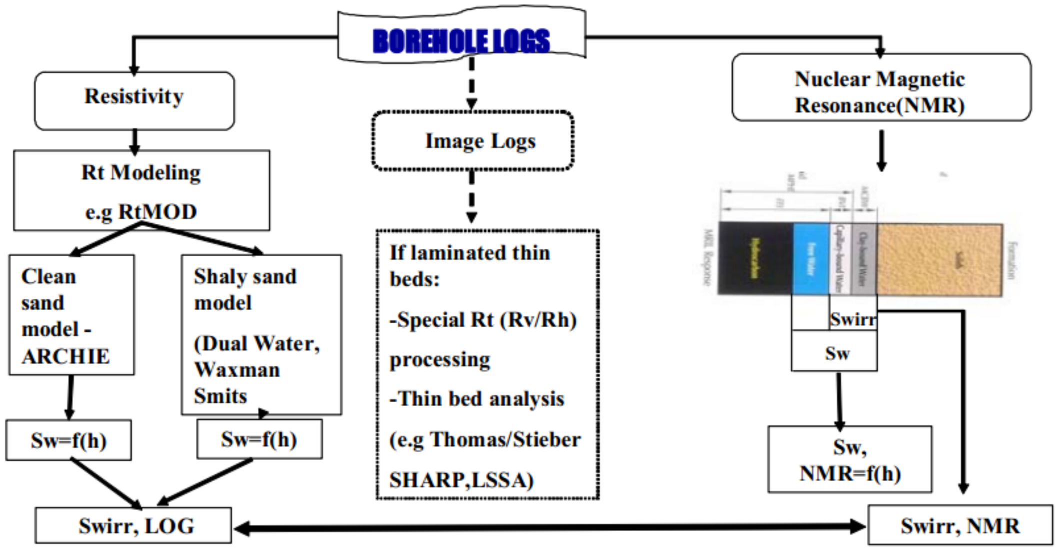


Figure 5 - Workflow for the evaluation and reconciliation of irreducible water saturation (Swirr) from Resistivity Logs and NMR Logs

LRLC reservoirs nowadays should not be neglected as it can become a potential production prospect as said by Stolper, 1994, recently the worldwide production and evaluation of these low-resistivity intervals has created and an awareness of their importance.

2.10 Resistivity Measurement

To develop an understanding of how logging systems respond to various types of rocks the manner in which pores are interconnected must be visualized. The simplest system to imagine is unconsolidated sand as shown below. In such a rock, the sand grains are piled on top of each other and the pore system is the space remaining between grains.

Resistivity is defined as the ratio between voltage and current. For some range of voltage, the Ohm's Law can be used to predict the behavior of the material. Every material has their resistivity and conductivity value which is the ability to transmit electrons. In order to apply this concept in reservoir, Archie's Laws had been developing to develop empirical relationships between water resistivity, porosity, and water saturation.

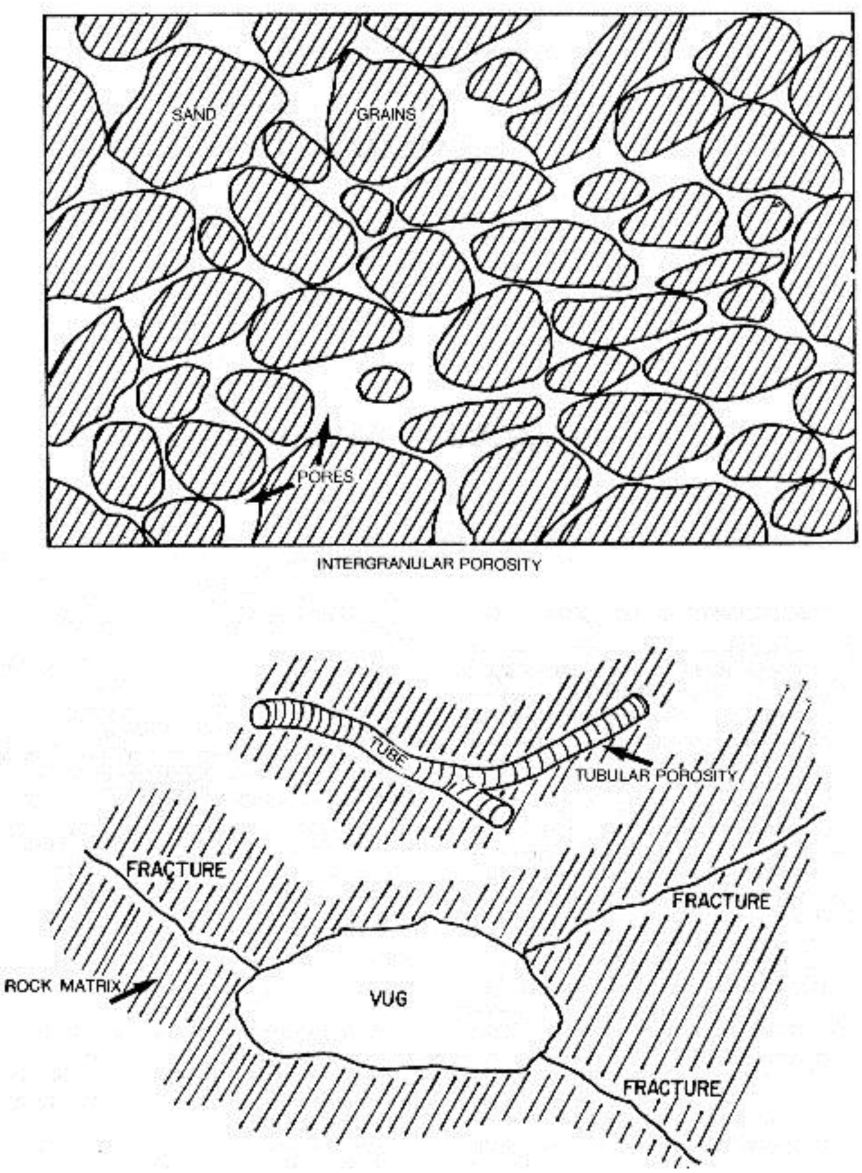


Figure 6 - Various pore geometries have different effective path length

The factors that directly affect resistivity are voltage and currents. However, there are many other factors that can affect resistivity one of which is the temperature. In electrical instrument, the value of a resistor changes with changing temperature mainly due to a change in the resistivity of the material caused by the changing activity of the atoms that make up the resistor.

Materials which are classed as conductors tend to increase their resistivity with an increase in temperature. Insulators however are liable to decrease their resistivity with an increase in temperature.

The reasons for these changes in resistivity can be explained by considering the flow of current through the material. The flow of current is actually the movement of electrons from one atom to another under the influence of an electric field. Electrons are very small negatively charged particles and will be repelled by a negative electric charge and attracted by a positive electric charge. Therefore if an electric potential is applied across a conductor electrons will "transfer from atom to atom towards the positive terminal.

Only some electrons are free to migrate however. Others within each atom are held so tightly to their particular atom that even an electric field will not dislodge them. The current flowing in the material is therefore due to the movement of "free electrons" and the number of free electrons within any material compared with those tightly bound to their atoms is what governs whether a material is a good conductor (many free electrons) or a good insulator (hardly any free electrons). The effect of heat on the atomic structure of a material is to make the atoms vibrate, and the higher the temperature the more violently the atoms vibrate.

In a conductor, which already has a large number of free electrons flowing through it, the vibration of the atoms causes many collisions between the free electrons and the captive electrons. Each collision uses up some energy from the free electron and is the basic cause of resistance. The more the atoms jostle around in the material the more collisions are caused and hence the greater the resistance to current flow. In an insulator however, there is a slightly different situation. There are so few free electrons that hardly any current can flow. Almost all the electrons are tightly bound within their particular atom. (Coates E. , 2011)

CHAPTER 3 METHODOLOGY

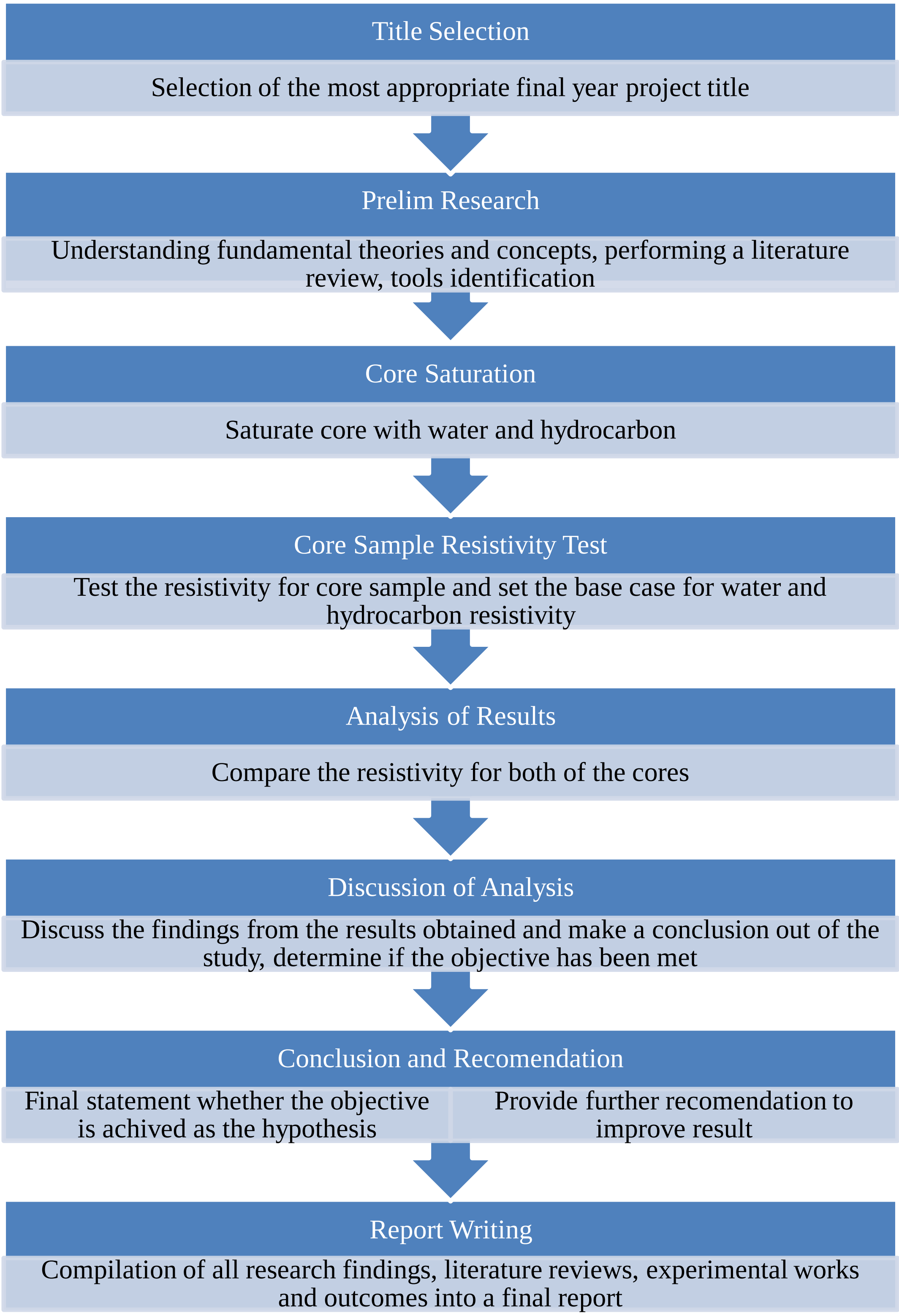
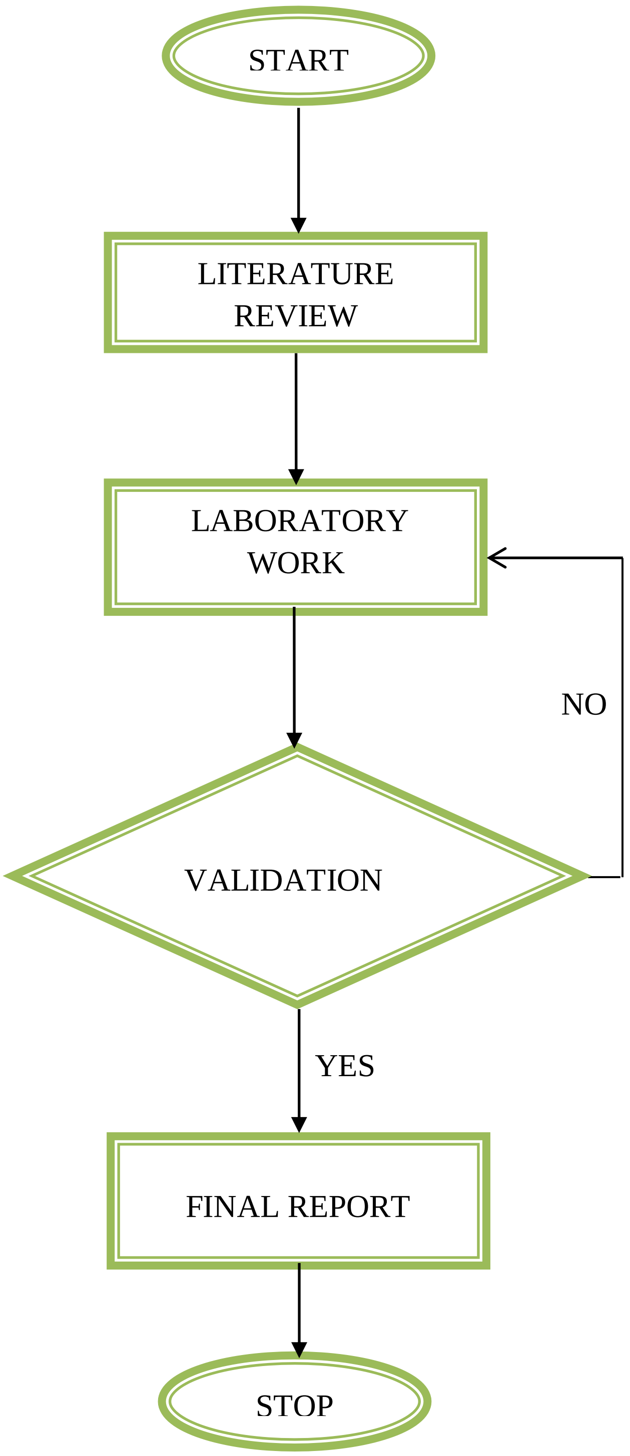


Figure 7 – Methodology

3.1 Process Flow



- Preview / Analysis problem
- Identify the problem faced from LRLC pays
- Identify the potential of NMR tools
- Fundamental studies from references and journals

- Do the lab work
- Identify saturated core sample resistivity using conventional resistivity test
- Identify fluid in core sample using result from conventional method
- Identify the fluid in saturated core sample using NMR tools
- Identify any errors occur during the lab work
- Identify whether the result is valid or not valid base on theory

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- Report on the potential of using NMR as alternative to conventional logging method
- Recommendation on operation and safety requirements

Figure 8 - Project Process Flow

3.2 Project Activity

The research will be a laboratory type research where core sample will be saturated and desaturated with water and hydrocarbon. Then resistivity test and NMR test tools will be conducted on the saturated core sample.

3.2.1 Step of Research

1. Firstly, best core sample that represent the LRLC reservoir will be chosen.
2. The core sample is desaturated to remove any content in the core.
3. The core will be saturated with water and hydrocarbon.
4. The saturated core will be tested using Autolab to acquire the resistivity.
5. The result will be evaluated and fluid in the core will be interpreted based from the result

3.3 Detailed procedure

3.3.1 Selecting suitable cores

Porous sandstone are chosen as it is easier to be saturated and more guarantee to be wholly saturated with the desired fluid.

3.3.2 Vacuum Saturation

1. 2 empty cores each with 1inch diameter are prepared for saturation.
2. 2 fluids are put into two beakers and labeled as Beaker A: Core Saturated with distill Water and Beaker B: Core Saturated with Crude Oil.
3. The experiment is conducted by using Beaker A first.
4. The reservoir tank of the Vacuum Saturator is filled with the fluid that wants to saturate with.
5. The core is put inside the reservoir tank and let to submerge in the fluid.
6. The reservoir tank is close by a lid.
7. The vacuum valve is opened and the pressure gauge valve is closed.
8. The pump is started and the pressure is increased until the desired pressure.

9. The machine is operated until the core is fully saturated with the fluids minimum is 6 hours.
10. After the fluid is saturated, the pump is stopped and the leftover fluid is put back inside the beaker. The saturated core is also put inside the beaker.
11. The reservoir tank is cleaned and left to dry.
12. Step 4 to 11 is repeated by beaker B

Figure 9 - Vacuum Saturator

3.3.3 Resistivity Measurement using Autolab

1. The experiment is started using beaker A
2. The core is removed from the beaker and put into 1inch rubber cone sleeve.
3. Then the rubber cone sleeve is fixed into the Sending Resistivity Transducer and the core and transducer is ensured to be in touch without any gaps in between.

4. Then the Receiving Resistivity Transducer is fixed into the other end of the rubber cone sleeve and ensures that the transducer is in touch with the core without any gaps in between.
5. All cables are connected to the specific connections and ensure that it is set to be in resistivity mode.
6. The Autolab machine power is switched to on and the computer also switched to on.
7. Set the desired frequency of Autolab.
8. The Autolab Software is opened in the computer and data required are inputted into the software.
9. After all required data have been inputted, the machine is run, and result is observed and recorded in the software.
10. When the run is done, the results are saved and the experiment is repeated for beaker B.

Figure 10 - Autolab Head (Transducers, Rubber Sleeve)

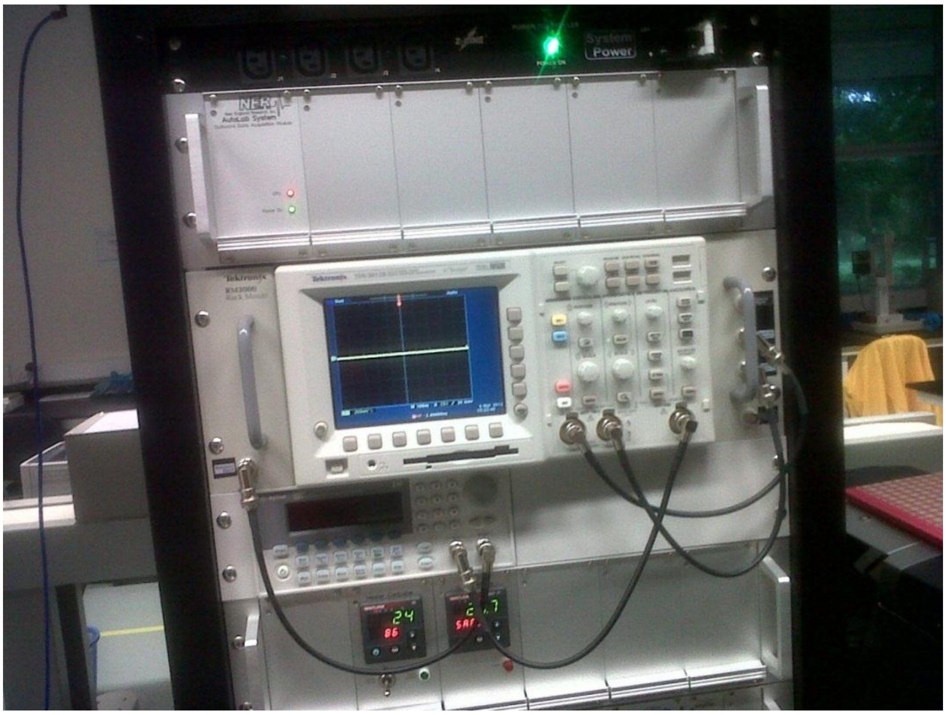


Figure 11 - Autolab Recording Machine

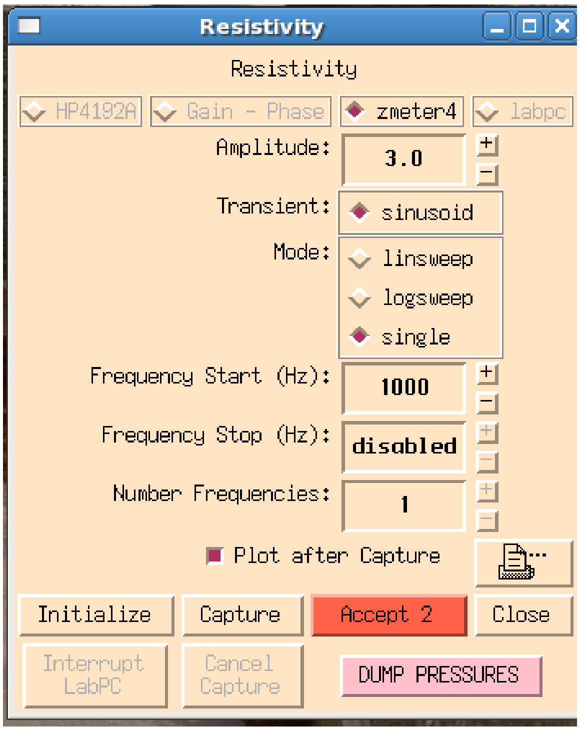


Figure 12 - Resistivity Inputs

3.3.4 Desaturation

Core is placed in centrifugal machine to desaturate.

3.4 Trip to PETRONAS Research Sdn. Bhd. (PRSB)

Figure 13 - NMR Main Unit

Figure 14 - NMR Cooling Unit

The trip is held to give an introduction to the NMR machine in PRSB, Bangi. The NMR machine is under the custody of Mr. Nizam (Senior Researcher, PRSB).

3.5 Gantt chart

No.	Activities /Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Selection of Project Topic														
2	Basic Data Gathering														
3	Preliminary Report Submission														
4	Detail Studies on T1/T2														
5	Familiarization of NMR Derived Porosity & Relaxation Properties														
6	Methodology Studies														
7	Proposal Defence and Progress Evaluation														
8	Studies on Equipment/Software Required														
9	All Results Gathering														
10	Draft Interim Report Submission														
11	Submission of Interim Report														
12	Oral Presentation														

Figure 15 - Gantt chart for 1st Semester

No.	Detail/ Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14
1	Project Work Continue	■	■	■					Mid-Semester Break							
	Lab booking and tools and item preparation															
2	Submission of Progress Report 1				●											
3	Project Work Continue				■	■	■	■								
	Core sample resistivity test using conventional method															
4	Submission of Progress Report 2									●						
	Analysis of result from resistivity test															
5	Seminar (compulsory)										■	■	■			
5	Project work continue									■	■	■	■			
6	Poster Exhibition											●				
7	Submission of Dissertation (soft bound)												●			
8	Oral Presentation														●	
9	Submission of Project Dissertation (Hard Bound)															●

Figure 16 - Gantt chart for 2nd Semester

CHAPTER 4 RESULT AND DISCUSSION

4.1 Result

4.1.1 Single Resistivity Plot

Table 1 – Single Plot - Real Resistivity (Ohm.m)

Amplitude	0.5	1.0	3.0
Distill Water	42.0075	49.2581	49.2581
Oil	82.7409	75.1505	76.2052

Table 2 - Single Plot- Imaginary Resistivity (ohms)

Amplitude	0.5	1.0	3.0
Distill Water	6317.19	7430.43	7407.56
Oil	8295.19	7534.22	7639.96

4.1.2 Linear Resistivity Plot

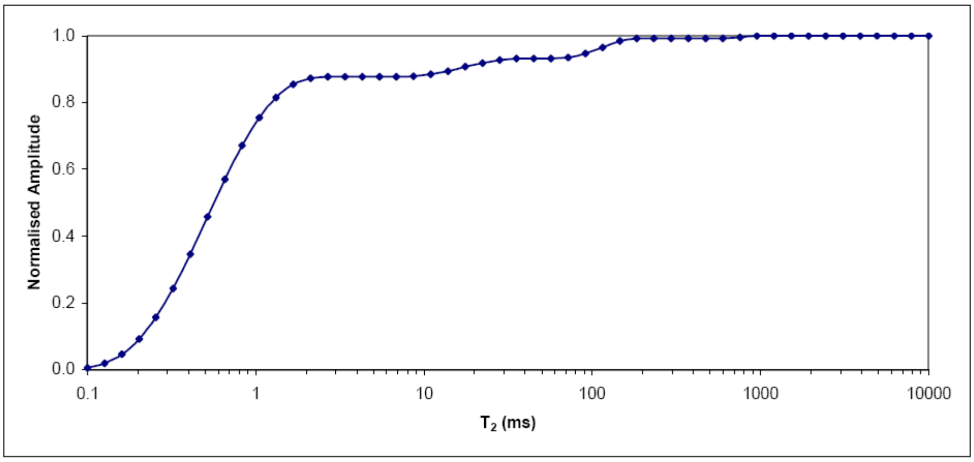
Table 3 - Linear Plot- Real Resistivity (Ohm.m)

Amplitude	0.5	1.0	3.0
Distill Water	38.4637	49.7423	32.3812
Oil	59.0767	50.1078	48.7319

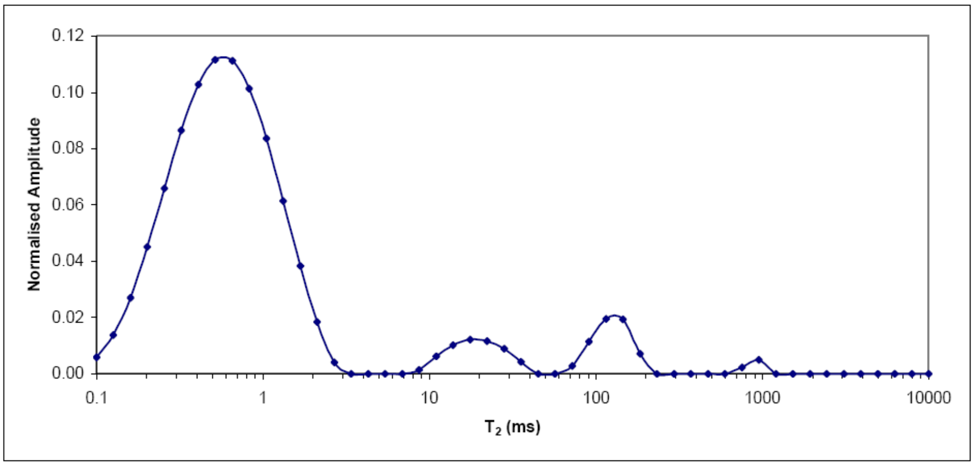
Table 4 - Linear Plot- Imaginary Resistivity (ohms)

Amplitude	0.5	1.0	3.0
Distill Water	5784.27	7480.38	4869.57
Oil	5922.74	5023.56	4885.62

4.1.3 NMR Testing – Crude Oil Core Sample



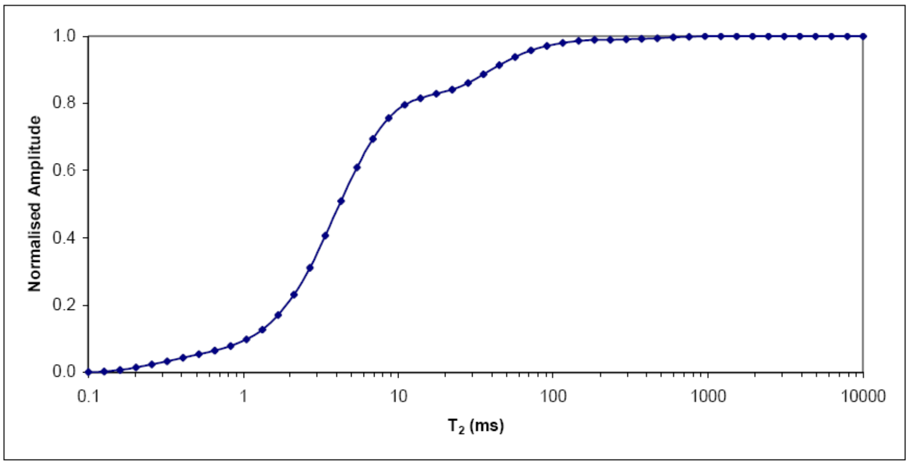
Cumulative T_2 Distribution



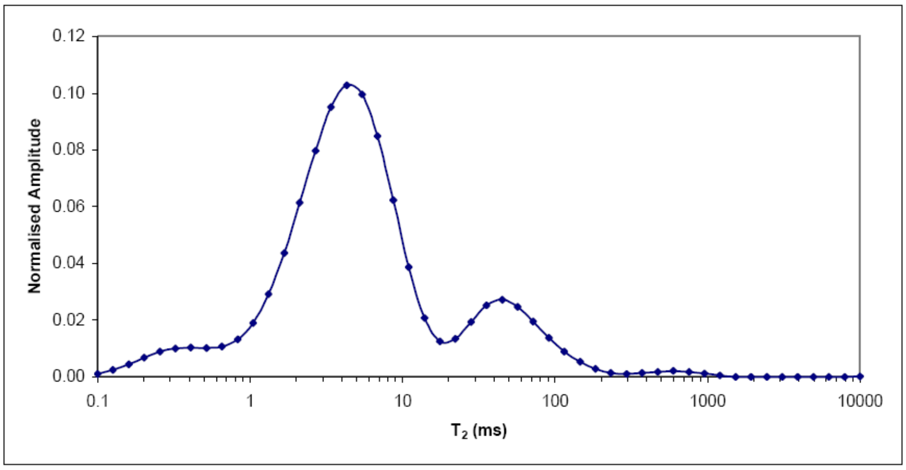
T_2 distribution

T2 Distribution peak for Crude Oil core sample is around 0.6 ms to 0.7 ms.

4.1.4 NMR Testing – Distill Water Core Sample



Cumulative T_2 Distribution



T_2 distribution

T2 Distribution peak for Distill Water core sample is around 7 ms to 8 ms.

4.2 Discussion

From the result obtained from Autolab, it is seen that the Imaginary resistivity yields almost the same result for both crude oil sample and distill water sample. This is true especially for the amplitude of 1.0. The Real resistivity however shows a distinguishing range between the results of crude oil sample and distill water sample.

The first method, the evaluation of core sample resistivity will yield the core sample resistivity in ohm-meter. This result should be able to be interpreted and at the end of the interpretation the fluid in the core sample should be identified as water and hydrocarbon. The resistivity for both fluids should be different in value since water is more conductive and thus will give lower resistivity while hydrocarbon is less conductive and thus will give a high resistivity value.

Distill water is used to represent the reservoir water that contains low mineral value which is the one that caused the low contrast effect. It is expected that the resistivity value for both fluid; distill water and crude oil, may not be very difference since there is no guarantee that the distill water is totally pure. This is because the beaker used and the vacuum saturation's reservoir tank had been filled with various kind of fluid and this therefore might leave some impurities to the distilled water. Thus the distill water may not become entirely pure and the resistivity value of the distill water acquired from the measurement might become lower than expected.

The crude oil on the other hand is taken from used projects. The oil had undergone various kind of project and therefore its true purity is already altered. Therefore the oil might become less resistive when measured. This two liquids overall will have an impact to the objective since in low contrast reservoir the phenomenon is that the water is very resistive as it is free from ion thus it makes the log reading to compare water zone and oil zone to be very hard. In order to improve, various type of water can be tested for resistivity measurement so that it can be seen that various type of water can give different resistivity reading and it will be possible for water to have a near resistivity value to crude oil.

The method of saturation used is the vacuum saturation method. This is based on the principle that the core when placed in the vacuum container will create a high pressure difference between the pore inside the core and the pressure outside the core. So the fluid will enter into the core since the pressure outside is greater than the pore pressure inside the core. The core will still be saturated if it is just leave to be submerged in the fluid that wants to be saturated but the core would probably not fully saturated with the fluid. Only the near surface pore will be saturated. This is because there are other factors such as the friction factor, the pore pressure, the capillary effect that makes the fluid outside needs enough pressure and energy to fully saturate the core. On the other hand, vacuum saturator may not fully saturate the core. Core with very little porosity and with small pore spaces may require higher more effective saturation method to fully saturate the core. It is impossible to fully saturate this type of core with crude oil since crude oil is viscous. There had been cases where when the core is saturated with crude oil using the vacuum saturation only the near surface pore is saturated. The inside of the core is not saturated. This can be seen by slicing the core section and the trace of oil cannot be seen in the center of the core. However this can be improved by using high permeability, high porosity core and crude oil with higher API degree. This can also be improved by running the vacuum saturation longer minimum for 6 hours.

The resistivity measurement does not fully reflect the resistivity measured using logging tools in the well bore. This is because in the well bore, there are many things that can become a factor to the resistivity measured. Such factors are like mud cakes drill cuttings and drill mud. Resistivity also affected by temperature. In this case the experiment conducted neglect the temperature since Autolab can only provide measurement in the room temperature. The experiment is limited by the machine capabilities. The reservoir temperature would be known to hold higher temperature thus the resistivity acquired might be difference. The degree of impact of temperature on different fluid is still unknown and need further research. Thus it is never certain that temperature will cause higher impact on resistivity measurement on water or vice versa. This is also same to the crude oil.

The Autolab machine uses alternating current and thus specific frequency need to be setup in order to come up with the resistivity. This is because resistivity is also related to the frequency. In this case, the machine is limited to frequency ranging from 1Hz to 100 kHz. 100 kHz is chosen as the frequency to be used since in the real resistivity logging tool frequency ranging from 500 kHz to 700 kHz is used. Higher frequency can make the reading to be more accurate. The transducers will emit higher frequency signal to the core and this means that a very fine reading is made compare to the lower frequency signal. As pore space is very small thus higher frequency signal may detect the fluid in the smallest pore size pore spaces.

The cores used are also not cleaned before saturating with distill water and crude oil. The cores might initially have some fluids inside which can affect the saturated fluids. The core should be cleaned first by injecting hydrogen or saturated with distill water, then desaturate and then leave to dry. Then only the cores are saturated with the desired fluid. This will ensure the pore spaces of the core cleaned and dry.

There are many ways designed to encounter and evaluate the low contrast reservoir. In general, we can group the alternatives into three groups which are first by changing the formation to improve it. Example for this technique is by altering the water that is causing the low resistivity contrast. Chemicals can be injected to improve the water resistivity so that the difference in resistivity clearly seen. The second group is by using improved methods and tools. Example for this group is by designing new tools such as NMR that is not affected by the resistivity difference thus give better data for interpretation. The third group is by improving the interpretation method. This can be done by researching more on the LRLC reservoir characteristics.

4.3 Expected Result

From the Autolab, the resistivity difference between both of the core would be small. Distill water is very pure and would contain almost none impurities. Therefore the conductivity of distill water would be low and the resistivity would be high. Crude oil is an insulator. It is known to be resistive.

Result from NMR experiments to determine the T2 value for various type of fluid also show that NMR can distinguished the fluid in the formation.

CHAPTER 5 CONCLUSION AND RECOMMENDATION

In conclusion, Low Resistivity Low Contrast reservoir should not be abandoned. Various methods had been develop and proven to be effective in resolving the problem caused by LRLC formations.

It is possible for water to be resistive and the resistivity contrast between the water and crude oil to be not so much different in the resistivity logs. Therefore, engineers should not only rely only in one method but try to evaluate using multiple methods so that the evaluation will be very precise and accurate.

NMR tool can be used as an alternative to conventional logging tool to evaluate LRLC pays more effectively and accurately. The tools can also be combined with other conventional logging tools to give better result and interpretation.

With the development and advancement in NMR technology, it would be possible to use NMR along with other conventional tool. This will later provide quality data for the engineer to do formation evaluation.

The project can be improved further by comparing real LRLC core sample that will best represent the real LRLC conditions. This project can be also improved further by conducting several tests on many types of LRLC cores to see the effect of each LRLC geological conditions.

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APPENDICES

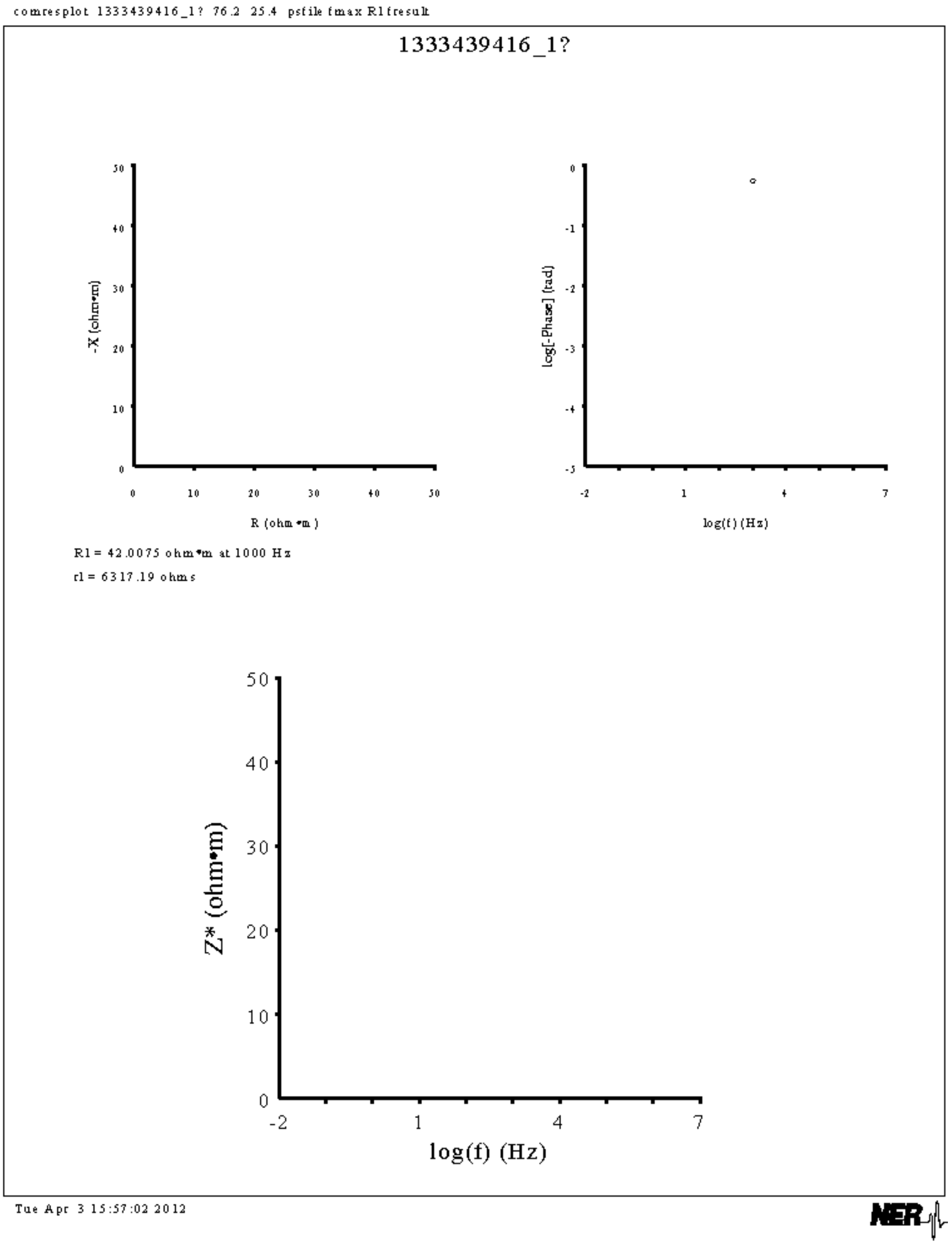

Figure 17 - Single Resistivity Plot, Distill Water, Amplitude 0.5

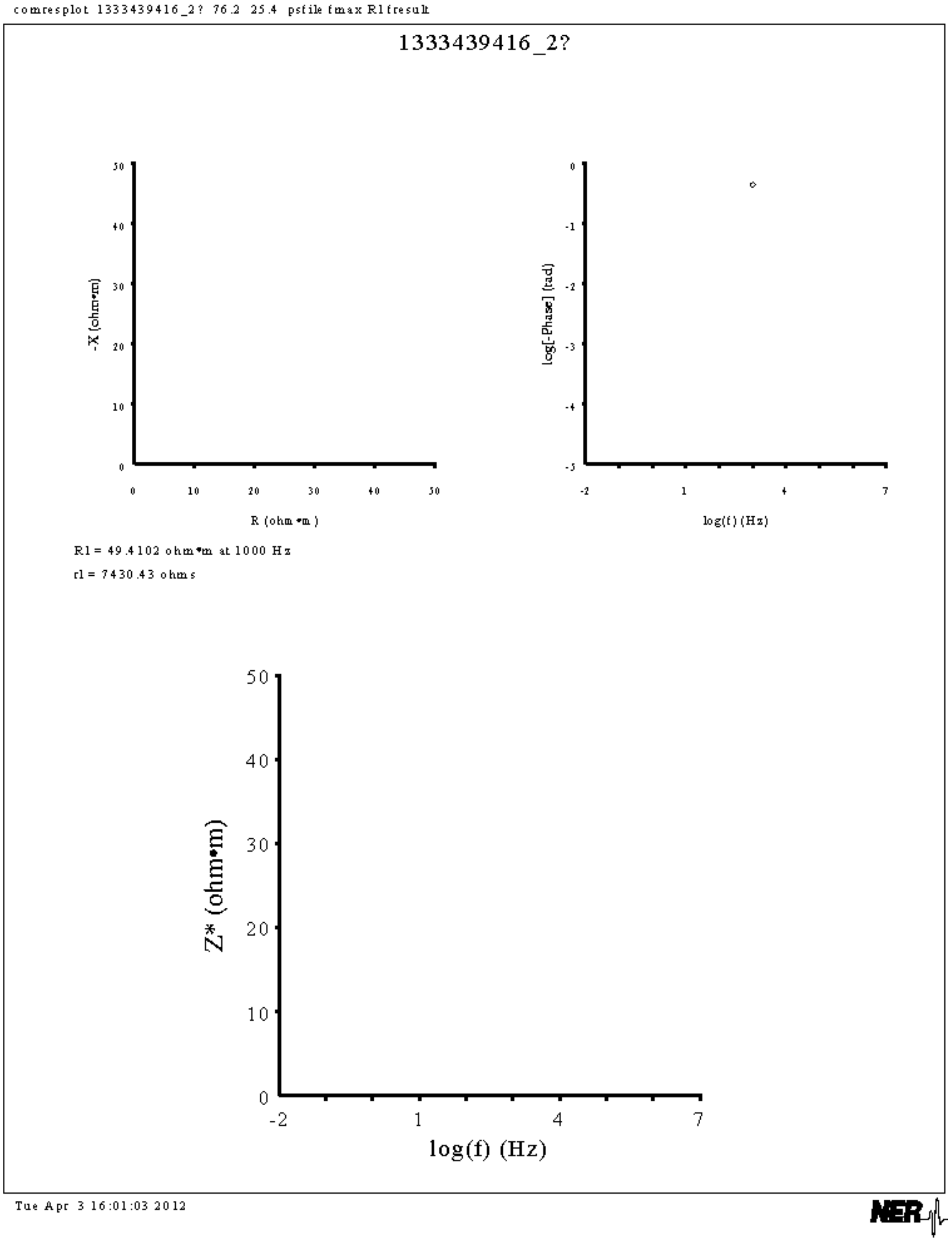

Figure 18 - Single Resistivity Plot, Distill Water, Amplitude 1.0

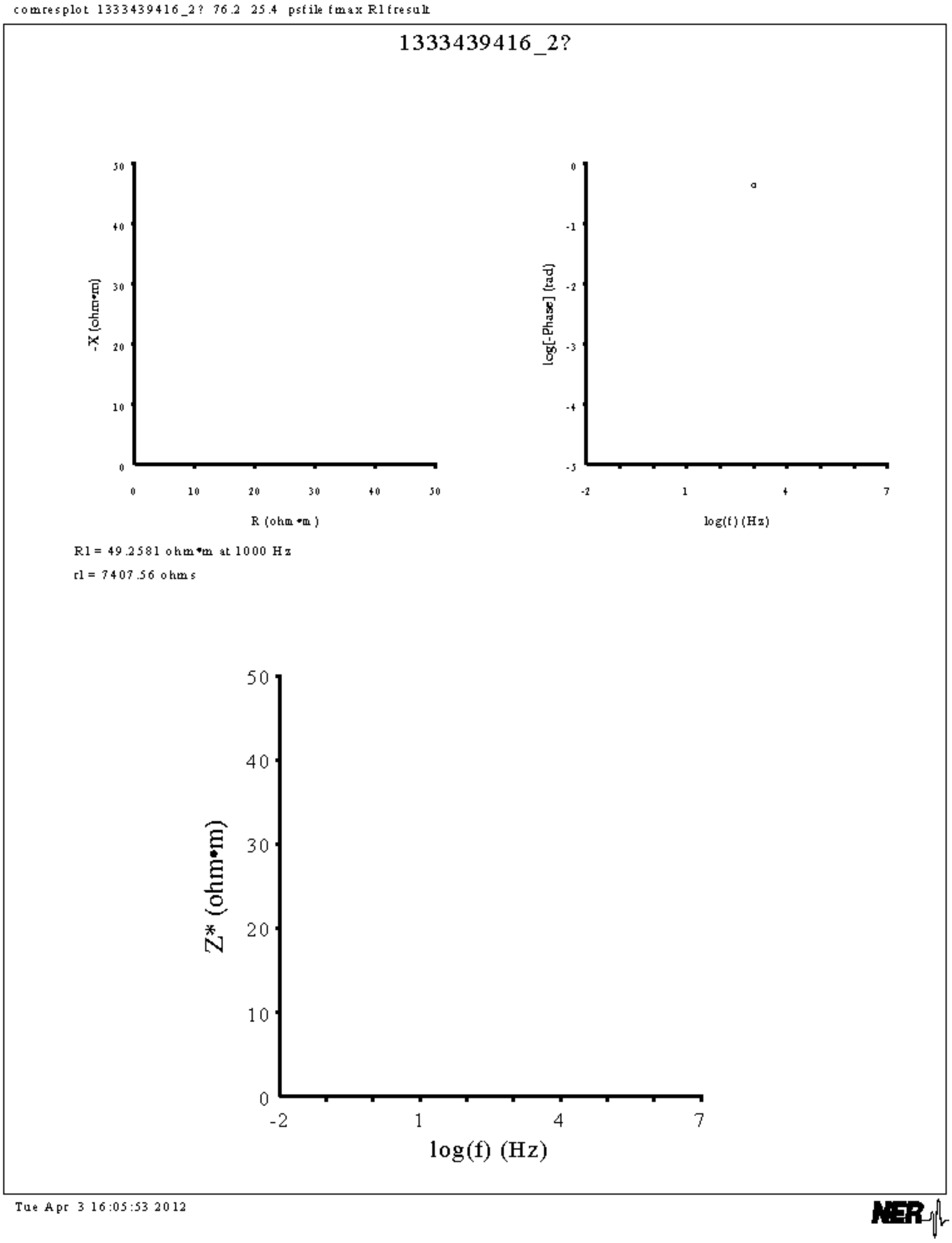

Figure 19 - Single Resistivity Plot, Distill Water, Amplitude 3.0

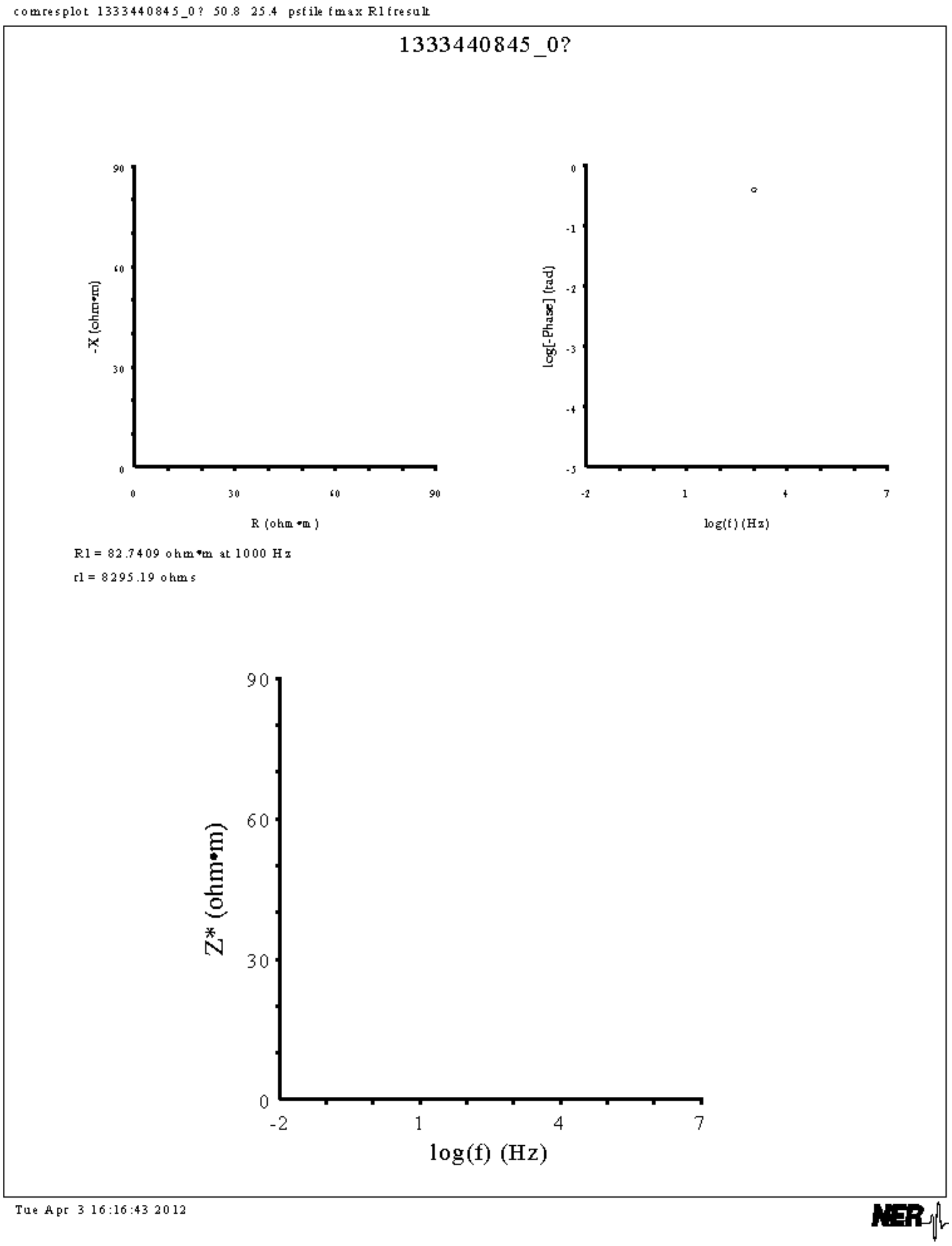

Figure 20 - Single Resistivity Plot, Oil, Amplitude 0.5

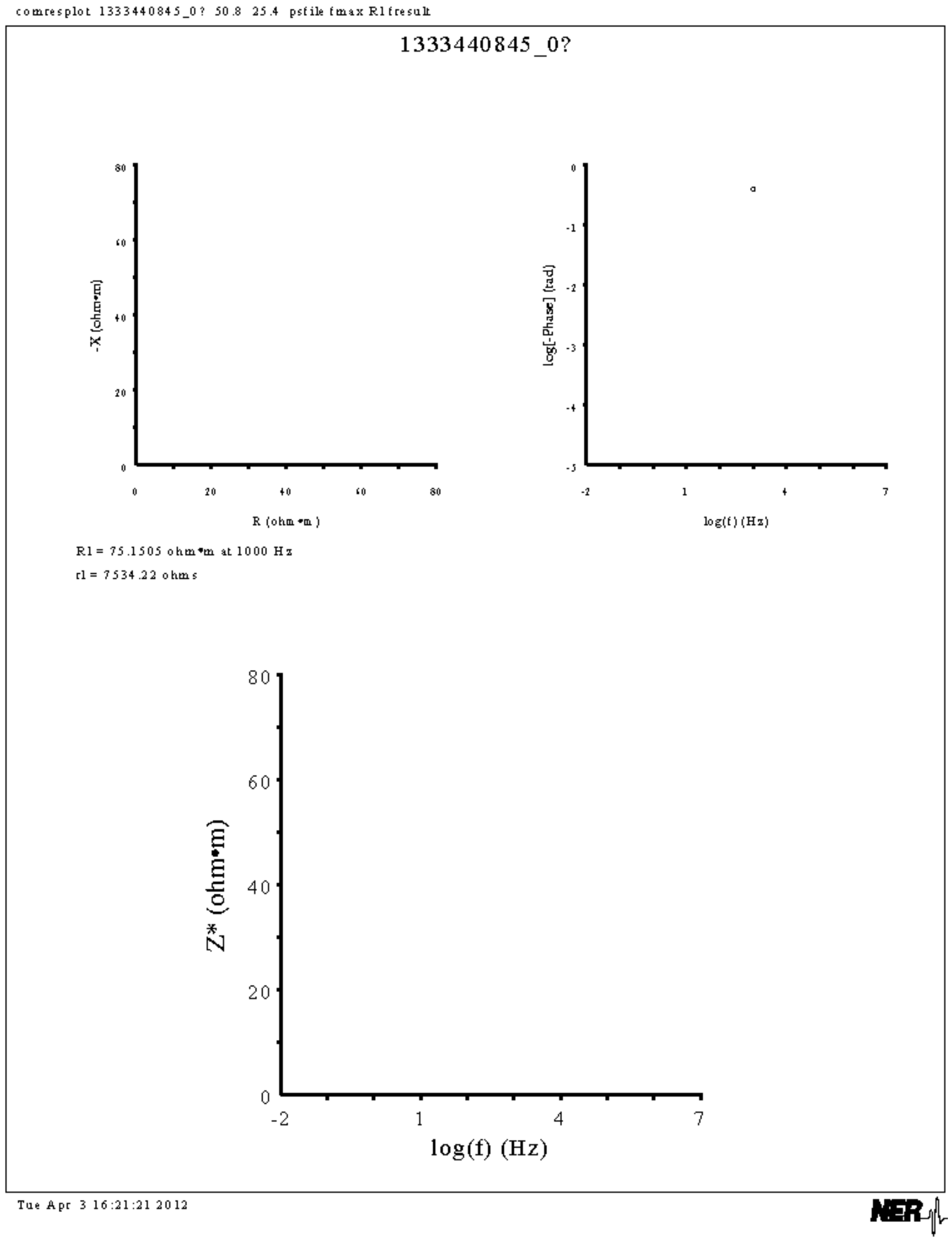

Figure 21 - Single Resistivity Plot, Oil, Amplitude 1.0

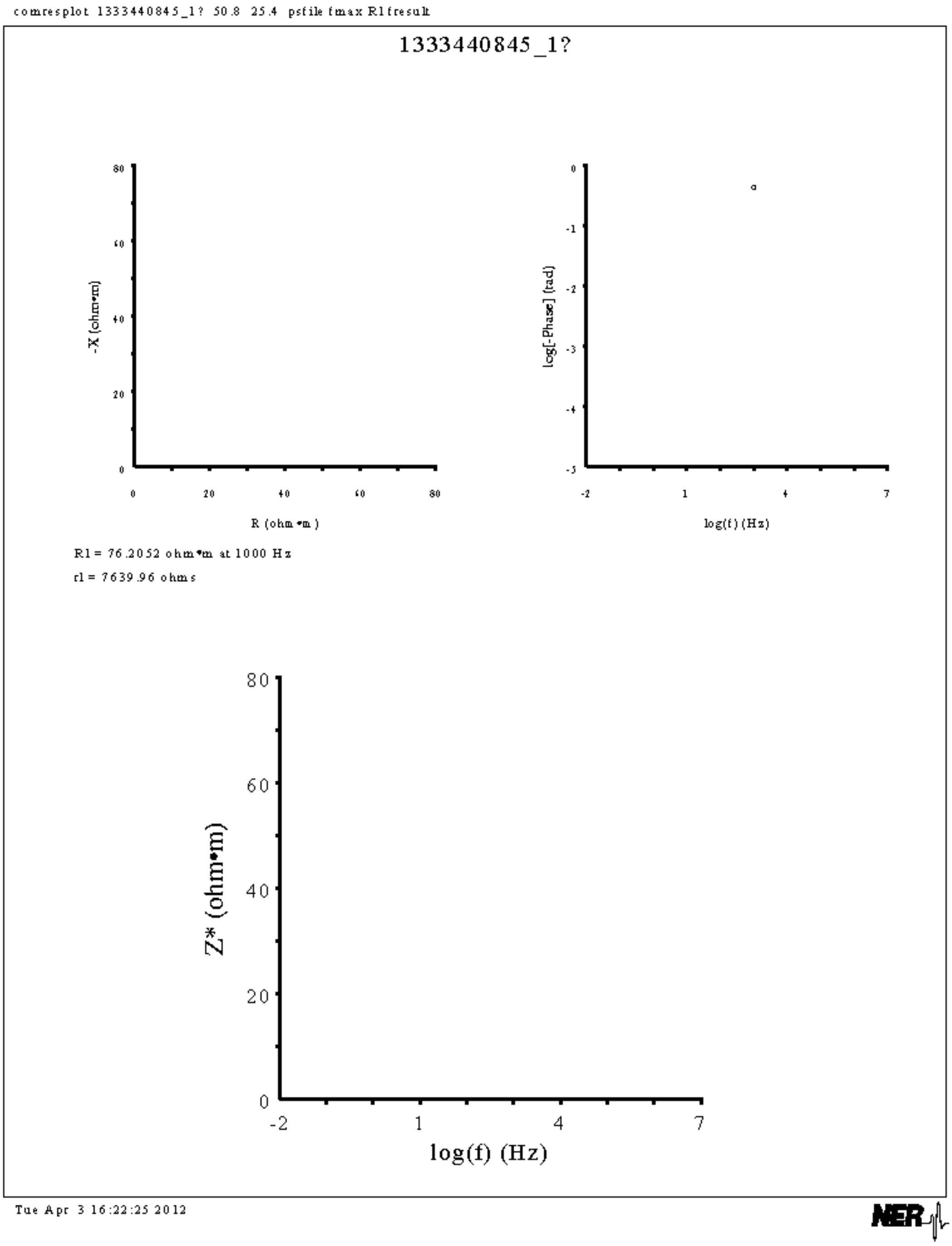

Figure 22 - Single Resistivity Plot, Oil, Amplitude 3.0

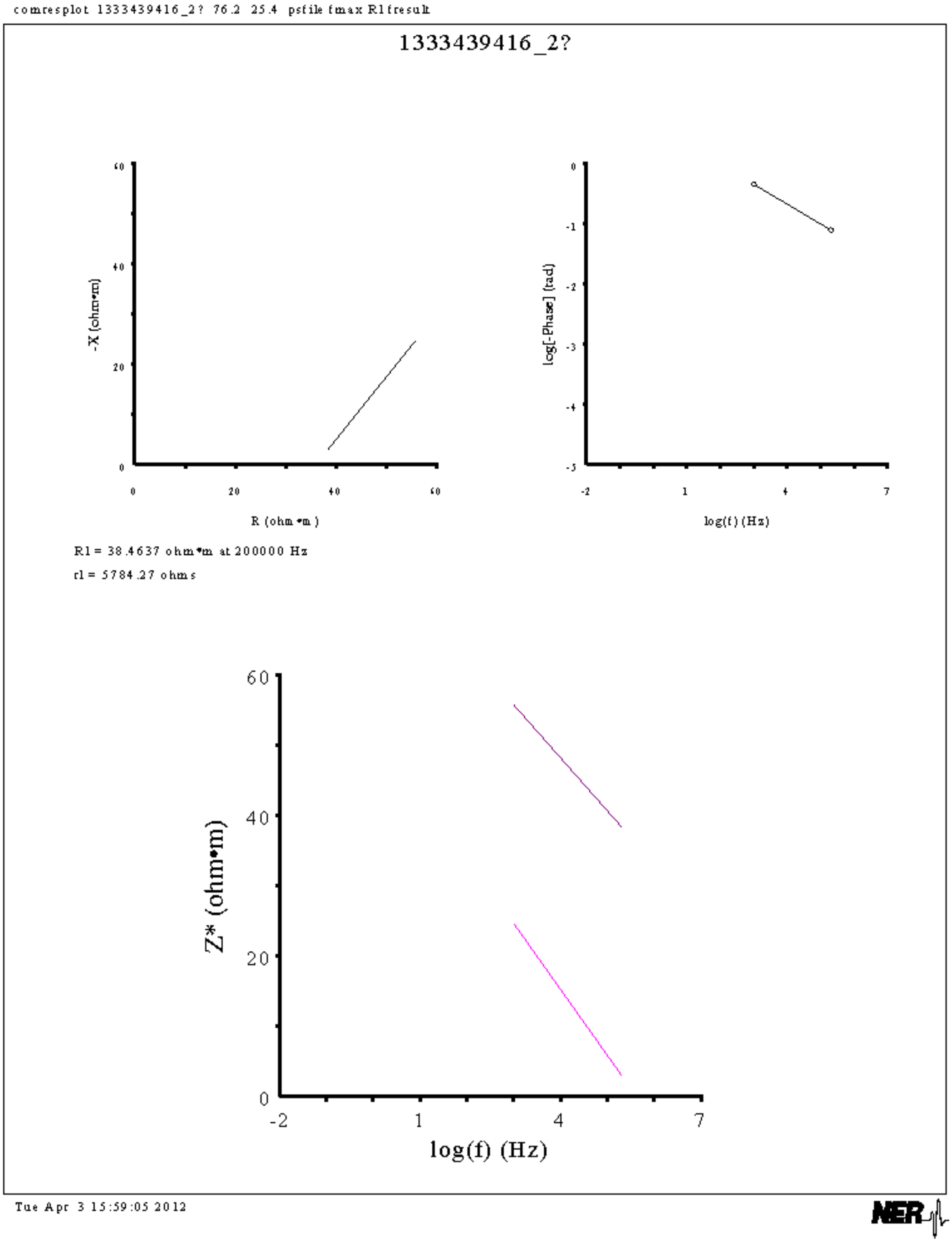

Figure 23 - Linear Resistivity Plot, Distill Water, Amplitude 0.5

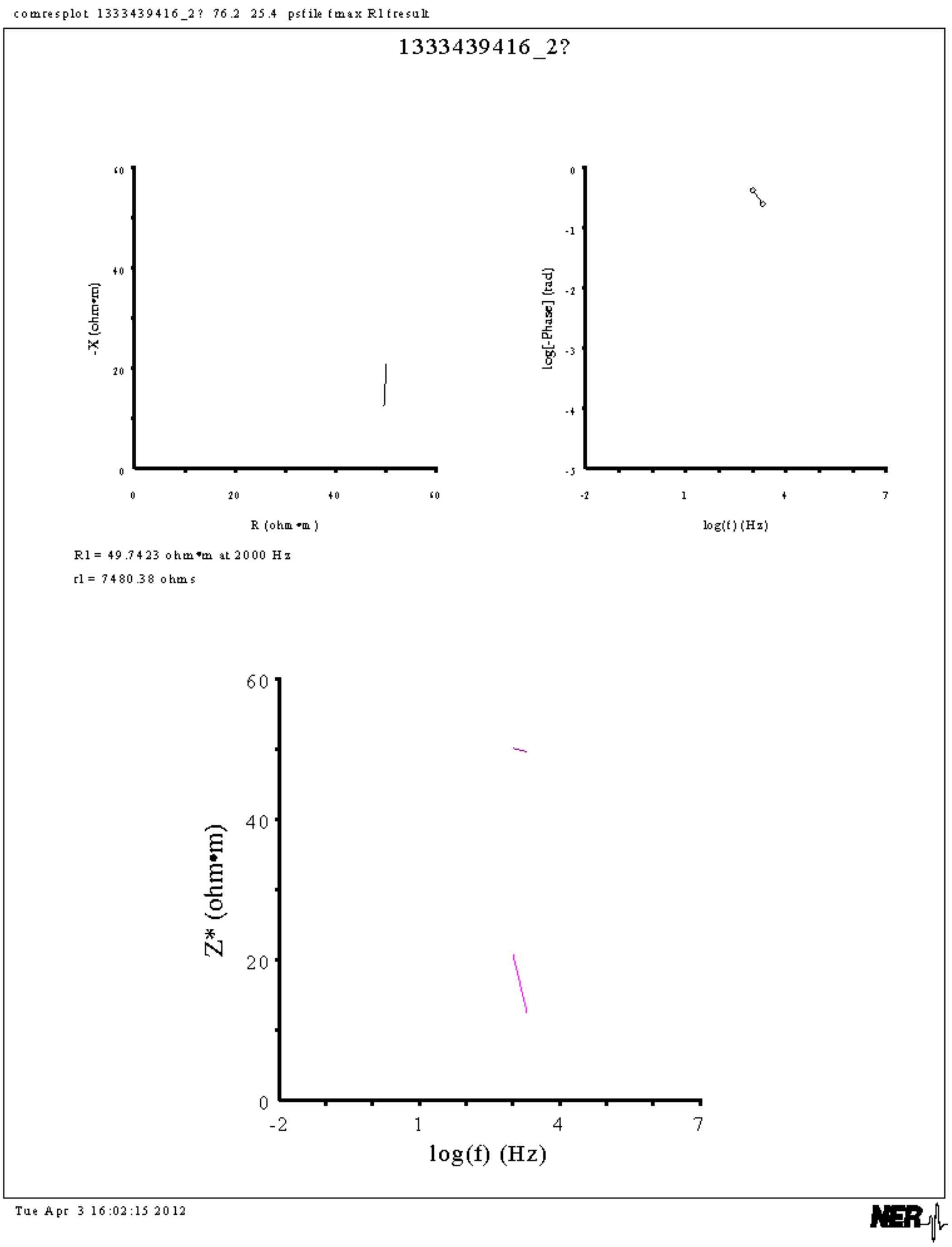

Figure 24 - Linear Resistivity Plot, Distill Water, Amplitude 1.0

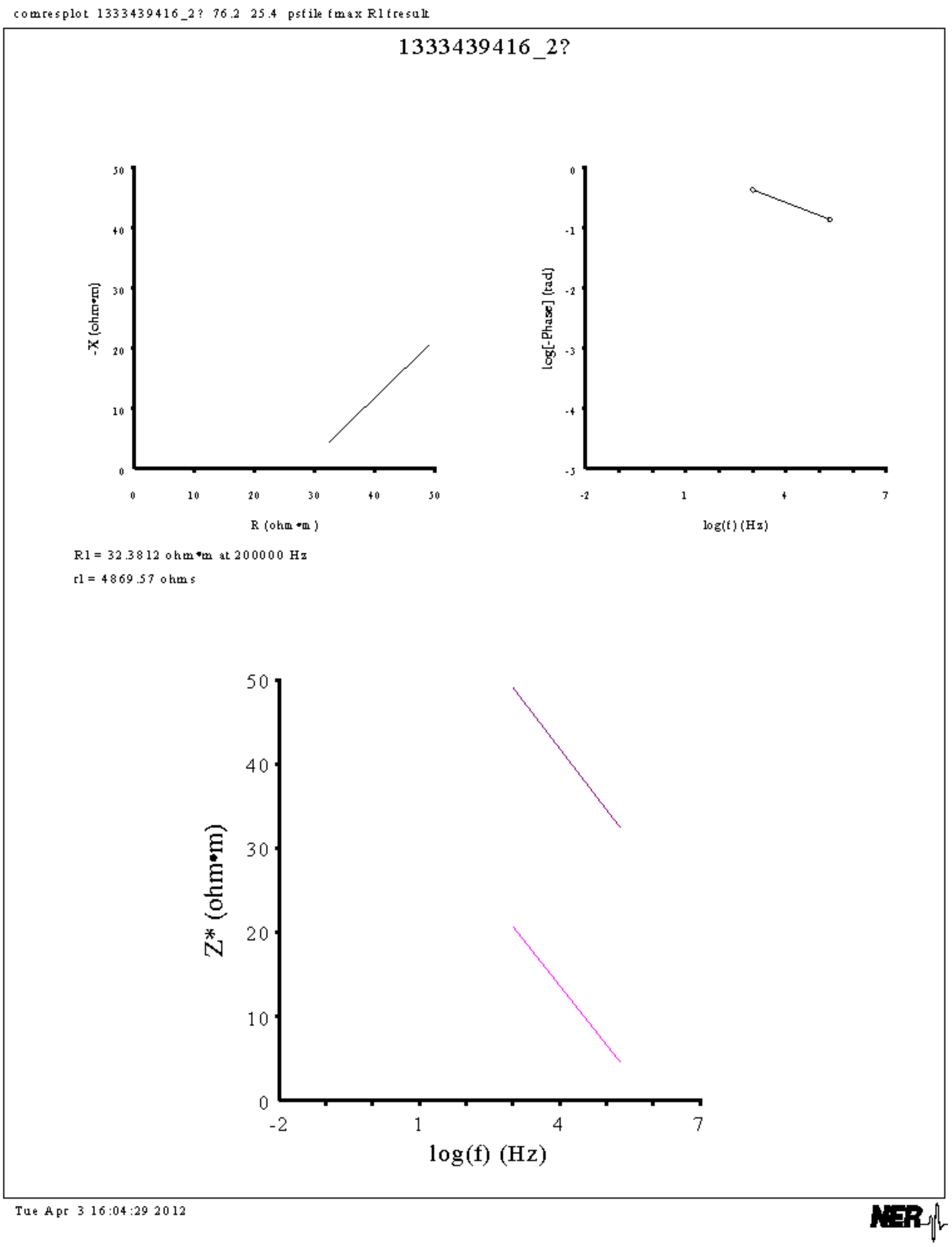

Figure 25 - Linear Resistivity Plot, Distill Water, Amplitude 3.0

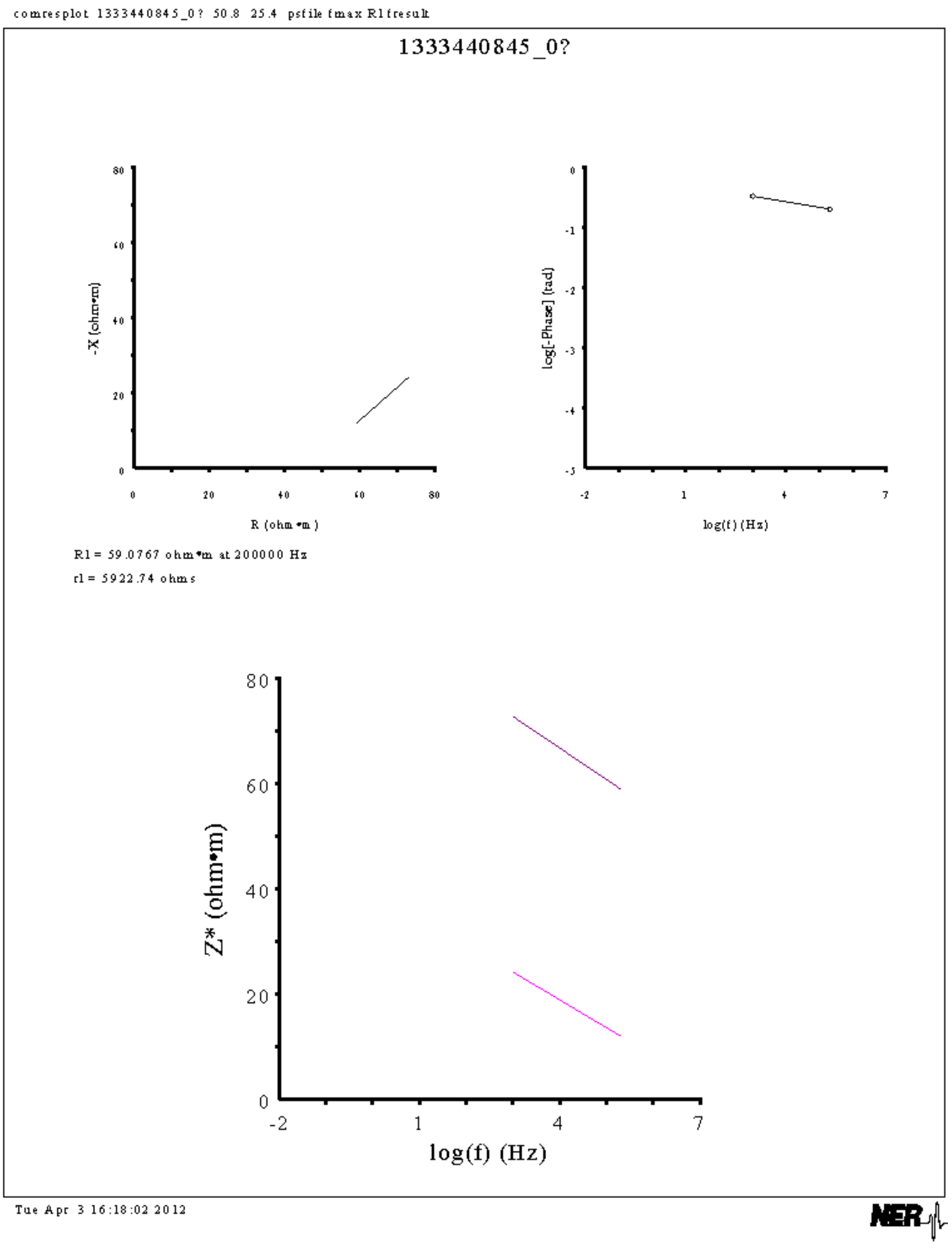

Figure 26 - Linear Resistivity Plot, Oil, Amplitude 0.5

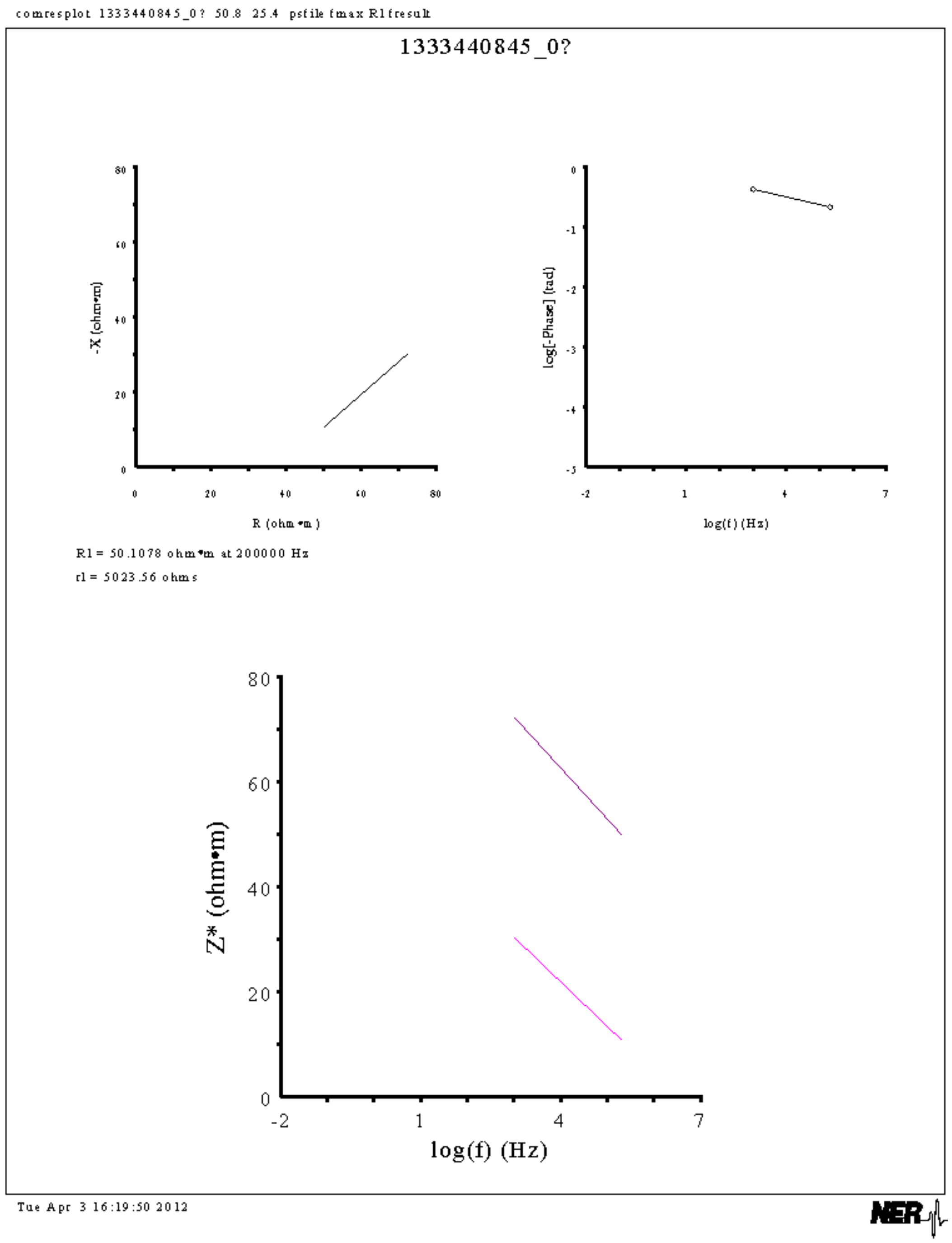

Figure 27 - Linear Resistivity Plot, Oil, Amplitude 1.0

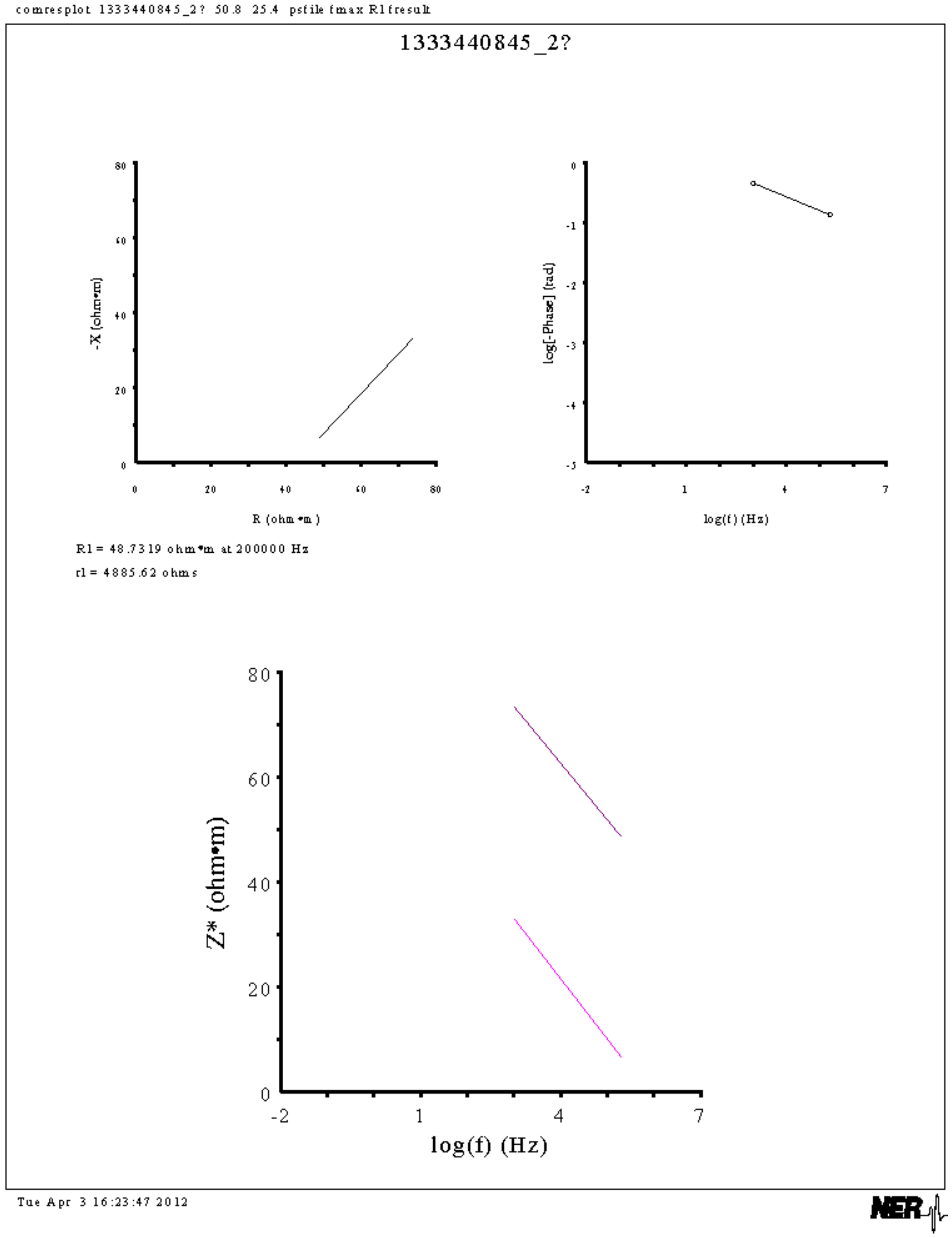

Figure 28 - Linear Resistivity Plot, Oil, Amplitude 3.0