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# USC PTE-461: Basic Formation Evaluation

**Fall Semester, 2013**

## ABOUT THE COURSE

This will be the 10th time that I have taught PTE-461.

PTE-461 is an applied course, teaching skills used by professional Engineers, Geologists, Geophysicists and Petrophysicists, in the Exploration and Production (E&P) Departments of the Petroleum Industry, on a daily basis, to evaluate drilling wells, estimate reserves, and evaluate assets for acquisition and/or disposal. It is based on in-house training classes, developed for Chevron Overseas Petroleum, Incorporated, PT Pertamina, SANDIA National Laboratory, SEMM Logging, and The Lawrence Livermore National Laboratory, modified to accommodate the needs of an academic environment. The content changes, slightly each year, based on suggestions from former students and technology developments, as well as my own reactions to what appeared to go well and what did not. Hover, the same general format has been followed for the past nine years.

PTE-461 is designed for the skill sets possessed by seniors, incoming graduate students and honors juniors in a Petroleum Engineering or Geosciences program. Students not interested in a Petroleum E&P career may be better served by taking other classes, instead of PTE-461.

PTE-461 is a hybrid class, in that some students will be on-campus, while others will be participating via the USC Distance Education Network (DEN). In the past, PTE-461 has drawn DEN students from Calgary, Alberta, in the North to Ciudad Neuquen, in the Patagonian foothills of the Andes, of Southern Argentina and from Beijing, in the west, to Kuwait City, in the east.

The course is designed to accommodate a wide range of background, educational and experience levels. Students are encouraged to work in teams, just as they will do, once they finish school and enter Petroleum Industry E&P Departments.

Past PTE-461 classes have been very cosmopolitan. Experience levels have ranged from little to no Geoscience, or Petroleum Engineering exposure to petroleum industry veterans, with several years of practical experience. Education levels have ranged from Seniors and Honors Juniors to incoming MS and PhD candidates. Formal training backgrounds have covered Geoscience and most Engineering disciplines. Physicists, Chemists, and Applied Mathematicians are also welcome. My goal will be to keep the class level basic enough to accommodate the skill sets of those students with little or no Petroleum E&P background, while still keeping the class interesting for industry veterans. Students have come from: Afghanistan, Argentina, Canada, China, Columbia, France, Gabon, Ghana, India, Iran, Korea, Kuwait, Malaysia, Nigeria, Saudi Arabia, Syria, Thailand, Turkey and Venezuela, as well as the US.

PTE-461 is also very demanding: for the students, the Teaching Assistants, Graders, and the instructor. In sixteen weeks, this class covers the same material covered in twenty weeks, at quarter academic calendar schools, such as Cal Tech, Stanford, and UCLA. Those students *not willing* to commit themselves to attending class, reading the assignments, completing homework assignments on time, and keeping up with the pace of PTE-461 should consider other classes. I do not want to waste my time, or that of the TA and graders, on casual students. As Juniors and above, I expect that you have all passed the Engineering and Science "Weeder Classes" and know how to manage Upper Level Engineering School Classes. I do not want or expect PTE-461 to be a "Weeder Class" for petroleum engineering.

PTE-461 is a "Learn by Doing" class. If you do not "do", you will not learn. The Review Questions and Homework Problems are "Learning Exercises". The two-hour exams and oral presentations are "Evaluation Exercises".

The class begins, with an explanation of what constitutes a petroleum reservoir. Fourteen weeks later the class has divided into teams that are using commercial formation evaluation (FE) software to evaluate data from unknown wells will reporting their results to the management of Flank Oil Company (FOCO), during Finals Week. This is what you will be doing in industry. In between these extremes, the physical and chemical foundations of the laboratory, wireline, and logging while drilling (LWD) measurements utilized in formation evaluation are developed and their practical applications examined. In-class and homework exercises are based on real problems actually faced, by the instructor.

## TEXT

I have yet to find the "Ideal" Petrophysics or Formation Evaluation text book. It probably does not exist. The following two books, however, come close.

Bassiouni, Z, 1994, **Theory, Measurement, and Interpretation of Well Logs**, Society of Petroleum Engineers, Richardson, TX.

Bateman, R. M., 2012, **Openhole Log Analysis and Formation Evaluation**, Society of Petroleum Engineers, Richardson, TX.

The Bassiouni book has been the course textbook, for the past 9 years (and beyond). The course lectures follow the outline of this book. It has very good developments of the physics and chemistry of the various petrophysical measurements utilized for Formation Evaluation (FE). However, there are serious gaps in subject matter coverage and the book is showing its age.

The Bateman book covers a broader range of subjects than the Bassiouni book, including measurements and FE targets not common when the Bassiouni book was written and published. However, the Bateman book's coverage of the physical and chemical basis of petrophysical measurements is not as good as the Bassiouni book coverage.

Both of these books are two of the few that I can say that I have red cover to cover (the Bassiouni book, for preparation of the PTE-461 class, 9 years ago, and the Bateman book as a reviewer for SPE publications, two years ago). Both books will be on the USC Science and Engineering Library Reserves shelf, available for three hour loans. Both books are also available from the library, to DEN students. Contact either DEN or the library for details about how you can gain access. Both books are also available for purchase from the Society of Petroleum Engineers (SPE) Bookstore, with a significant discount to SPE members and student members.

I have listed the Bateman book as the PTE-461 textbook and it is available from the USC bookstore. However, I will list reading assignment pages in both. I hope that at least some students will try both books and provide feedback as to which one was better for them. There are also other Formation Evaluation/Petrophysics references available on the USC Science and Engineering Library PTE-461 reserves shelf. I will reference them, throughout the course.

## COURSE OUTLINE

**Lecture 1: Introduction**

A. Class Description and Goals
B. The Drilling Well
C. What are Well Logs?
D. Role of Formation Evaluation/Petrophysics in The Petroleum Industry

E. What is Desired and What is Measured
F. Who are Petrophysicists and How do They Work
G. Well Logs and How They are Acquired
H. Uses of Well Logs
I. Historical Development
J. The Schlumberger Legacy

**Lecture 2: Petroleum Geology Lite**

A. Introduction
B. Minerals
C. Rocks
D. Reservoirs
E. Origin of Petroleum
F. Hydrocarbon Migration
G. Petroleum Reservoir Requirements
H. Atlas of Reservoir Type Examples
I. Bi-Modal Clastic Model

**Lecture 3: Petrophysics**

A. Definitions
B. Collection, Storage, Preservation, and Preparation of Rock and Fluid Samples for Laboratory Measurements
C. Routine Core Analysis
D. Maximum Likelihood, or Reduced Major Axis (RMA) Data Fitting Methods
E. Special Core Analysis Laboratory (SCAL) Measurements
F. Formation Factor and Resistivity Index
G. Capillary Pressure and Leverett J-Function
H. Elasticity and Elastic Wave Propagation
I. Acoustic Porosity Petrophysical Models
J. Fluid Measurements
K. Effects of Clay Minerals on Flow, Electrical, and Other Physical Properties
L. Shaly-Sand Petrophysical Saturation Models

**Lecture 4: Well Logging Environment**

A. Introduction
B. Wellsite
C. Wireline and Measurements While Drilling (MWD) Well Logs
D. Borehole Model
E. Environmental Effects and Corrections
F. Subsurface Temperatures

**Lecture 5: Resistivity Measurements**

A. Introduction
B. Electrical Measurement Log Curves
C. Historical Background
D. Electricity & Magnetism
E. Circuit Element Analogues
F. Intrinsic Material Properties
G. Guarded Sample Holders
H. Potential Theory and Resistivity Measurements
I. Surface Resistivity Methods
J. Subsurface Electrode (Galvanic) Resistivity Logs
K. EM Wave Theory
L. EM Surface & Airborne Measurements
M. Induction (EM) Logs

**Lecture 6: Spontaneous Polarization**

A. Introduction
B. Electrolytes
C. Spontaneous Potential
D. SP Mechanism
E. Nernst Equation SP Model to Estimate $R_{SP}$
F. SP $R_w$ Epilogue
G. SP as a Sand/Shale Indicator
H. SP Log Shale Volume Indicator

**Lecture 7: Natural (Passive) Gamma Radiation Measurements**

A. Introduction
B. Rationale for Petroleum Well Gamma Ray Logs
C. Natural Gamma Ray Log Operating Principles
D. The Gamma Ray Log as a Sand/Shale Discriminator
E. Gamma Ray Log Shale Volume Disclaimer

**Lecture 8: Density (Gamma Ray Scattering and Absorption) Measurements**

A. Introduction
B. Rationale for Running Petroleum Well Density Logs
C. Density Log Operating Principles
D. Density Log Sondes
E. Density Log Calibration
F. Density Log Statistical Measurement Ramifications
G. Density Log as a Porosity Tool
H. Lithology Determination - PEF, or Z Logs
I. Density Log Gas Effects
J. Effects of Clay Minerals
K. Density Log Source Issues
L. Discussion

**Lecture 9: Neutron Scattering, Absorption and Activation Measurements**

A. Introduction
B. Rationale for Running Petroleum Neutron Logs
C. Neutron Log Operating Principles
D. Neutron Porosity Log Sondes
E. Neutron Porosity Log Calibration
F. Neutron Porosity Log Statistical Measurement Ramifications
G. Migration/Slowing Down Distance Based Calibration
H. Salinity Effects
I. Neutron Log Gas Effects
J. Effects of Clay Minerals
K. Pulsed Neutron Capture Logs
L. Neutron Log Source Issues
M. Discussion

**Lecture 10: Acoustic Measurements**

A. Introduction
B. Rationale for Running Petroleum Acoustic Logs
C. Well-Shooting, Interval and average Velocities, and Time-Depth Models
D. Seismic Refraction
E. Continuous Velocity Logs (CVL)
F. Acoustic Log Tool Design Developments
G. From Seismic Refraction to Acoustic Logs
H. Acoustic Logs as Porosity Tools
I. Effects of Hydrocarbons
J. Effects of Clay Minerals

K. Disclaimer

**Lecture & Workshop 11: Routine Formation Evaluation (FE) Techniques**

A. Introduction
B. Log Analysis Protocol
C. Data acquisition
D. Cut-Off Conditions
E. Gross vs. Net Pay
F. Stock Tank Original Oil In Place (STOOIP)
G. Movable Oil Saturation
H. Advantages and Disadvantages of Routine FE Techniques
I. Workshop Examples
J. Discussion

**Lecture & Workshop 12: Reconnaissance and Over-Plot Interpretation Techniques**

A. Introduction
B. $R_{wa}$ Estimates
C. $R_o$ Log
D. $F_{xo}/F_s$ Log
E. $F_{xo}/F_t$ Log
F. MOP
N. Advantages and Disadvantages of Reconnaissance and Over-Plot Interpretation Techniques
O. Workshop Examples
P. Discussion

**Lecture & Workshop 13: Multiple Log Interpretation Techniques**

A. Introduction
B. Background
C. Two-Measurement Cross-Plots
D. Three-Measurement Cross-Plots
E. Discussion of Complex Lithology Interpretation Techniques
F. Workshop Examples
G. Discussion

**Lecture & Workshop 14: Pattern Recognition and Cross Plot Interpretation Techniques**

A. Introduction
B. Non-Linear Resistivity/Porosity (Hingle) Crossplots
C. Bi-Logarithmic Resistivity/Porosity (Pickett) Crossplots
D. Flushed Zone Resistivity-Porosity Crossplots
E. Iterative Crossplot Techniques
F. Advantages and Disadvantages of Crossplot $R_w$ & $S_w$ Interpretation Techniques
G. Workshop Examples
H. Discussion

**Lecture & Workshop 15: Shaly-Sand Interpretation Techniques**

A. Introduction
B. Clay Mineral Effects
C. Bi-Modal Model
D. Shale Volume Estimates
E. Porosity Tool Shale Responses
F. Porosity Tool Overlay Cross-Overs
G. Effective Porosity
H. Shaly Sand $S_w$ Estimates
I. Shaly-Sand Discussion
J. Workshop Examples
K. Discussion

**Lecture & Workshop 16: Gas Sand Interpretation Techniques**

A. Introduction
B. Gas Effects on Porosity Tools
C. Porosity Tool Overlay Cross-Overs
D. Porosity Estimate Gas Corrections
E. Gas Reservoir Saturation Estimates
F. Gas effects on Lithology/Porosity Cross-Plots
G. Shaly Gas Sand $S_w$ Estimates
H. Gas Reservoir Discussions

**Lecture & Workshop 17: Calibration and Data Quality Control**

A. Introduction
B. Calibration Philosophy
C. Accuracy vs. Precision
D. Primary, Secondary, & Tertiary Calibration Standards
E. Ad Hoc Field Calibration Checks
F. QA/QC Examples
G. Workshop Examples
H. Discussion

**Lecture 18: Mud Logging**

A. Background
B. Cable Tool Drilling & Driller's Logs
C. Subsurface Geology and Geologist's Strip Logs
D. Rotary Drilling
E. Enter Mud Loggers
F. Automated Drilling Parameter Measurements
G. Value of Mud Logs
H. Summary

**Lecture 19: Bypassed Pay: Cased-Hole Asset Tools**

A. Bypassed Pay Zones
B. Old Log Tricks
C. Second Generation Log Tricks
D. Modern Log Tricks
E. Pulsed Neutron Capture Logs
F. Cased-Hole Resistivity

**Lecture 20: Nuclear Magnetic Resonance (NMR) Logging**

A. NMR Background
B. Why Run NMR Logs
C. NMR Log Measurements
D. NMR Log Interpretation

**Lecture 21: Tough Logging Conditions & Measurements While Drilling**

E. Tough Logging Conditions
F. Measurements While Drilling
G. Horizontal Well Applications

## READING ASSIGNMENTS

All of the lectures and workshops will have reading assignments. Some will be in the Bassiouni or Bateman books. Some will be in DVD and/or hard copy reference materials passed out during class. Others will be in "Supplemental Lecture Notes and paper reprints posted on the PTE-461 DEN Website.

## TRAINING EXERCISES

In addition to the course lectures and examples, students will participate in in-class exercises, do homework exercises and answer review questions, all designed to develop a working knowledge of Formation Evaluation and prepare for the *Evaluation Exercises.* The weighting of the *Training Exercises* is:

- **Review Questions (10% of Final Grade)**
- **Homework (10% of Final Grade)**

While the cumulative weighting of the *Training Exercises* is only 20% of the final course grade, attempting to address the other 80% without the knowledge and skills learned from them will put the student at a severe disadvantage. Failure to complete these assignments will immediately put the student at 80%, or a low B letter grade, even if he/she "Aces" the "Evaluation Exercises". While undergraduates can absorb a "Gentleman's C", Graduate students cannot. Even for undergraduates, a low B letter grade, or worse, in a 400 level class, will not help you get into graduate school. In today's job market, a professional degree provides much grater security than a BS. That is why DEN students are giving up their evenings and weekends to get a professional degree.

## EVALUATION EXERCISES

The major difference between in-house and continuing education training and an academic course is *Evaluation*. For PTE-461, *Evaluation* is accomplished via four different mechanisms:

- **Two One-Hour Written Examinations (25% total of Final Grade)**
- **One Fifteen Minute ("Fifteen Minutes of Fame") Presentation (15% of Final Grade)**
- **Evaluation of other student "Fifteen Minutes of Fame" presentations (5% of Final Grade)**
- **Final Team Asset Well Appraisal and Report to Management (35% of Final Grade)**

**One-Hour Written Examinations**

This is the traditional academic evaluation technique. They will consist of short answer and numerical problems to evaluate the skills the students have picked up, from the lectures and workshops, reading assignments, review questions, and in-class and homework exercises. The first Hour Exam will cover the basic science behind Formation Evaluation measurements (i.e. Lectures 1 –10 & 18, Chapters 1 – 10, in the Bassiouni Text, or Selected Chapters in the Bateman book). The Second Hour exam will cover Formation Evaluation Analysis techniques (i.e., Workshops 11 – 17 & 19, as well as the rest of the Bassiouni book or selected chapters from the Bateman book).

**Fifteen Minutes of Fame (FMOF)**

This involves independent student research and a short (15 minute) presentation on a Formation Evaluation related subject, of interest to the student, *NOT* covered by the class. To prevent repetition, subjects will be reserved on a first-requested, first-served, basis. When I started Teaching PTE-461, these presentations were all individual. Because of class size, and limited time for the presentations, they have become, primarily, 2 -3 person team affairs. In the past a single grade was given for each team, so team members needed to help each other out for the benefit of the team. In response to complaints from past students, who felt that some of their team-members did not carry their fair share, students will be asked to rate their team partners. As a result the final FMOF grade will be a combination of the team presentation effectiveness and team effort. Oral presentations and written reports will be how you will be evaluated, in industry, not written examinations.

**FMOF Presentation Evaluations**

Once in industry, you will often hear presentations by colleagues and outside vendors. Your management will be looking to you to provide feedback about the material presented. For the FMOF exercise, you will be the audience for the presentation teams. You will need to tell the TA, Graders, and me what you thought of the presentations and whether or not the presenters effectively presented their message. Do not blow of this responsibility. Last year, some students did and were shocked to learn that this action lowered their final grade.

**Asset Appraisal Well Project (FOCO)**

The class will be broken up into 2 – 3 person teams (selected by lot, with English being the only common language) to evaluate a "drilling well" or a well selected for acquisition and/or divestment. Student teams will evaluate, using commercially available Formation Evaluation software, Library ASCII Log Standard (LAS) format well log datasets and other well & field information; and will prepare a short presentation of their results to "Management" of Flank Oil Company (FOCO). The FOCO presentations will take place on Tuesday December 17 (i.e., the next to the last day of Finals Week). ***DO NOT*** plan to leave campus for Winter Break, before Wednesday 18.12.13. The FOCO grades will be determined in the same manner as the FMOF.

## NOTE:

1. The class will meet every week, in the term, *including the October 1st class meeting*, which occurs during the Annual SPE ATCE Meetings, as well as any weeks, where the instructor must be out of town. Weeks when the Instructor must be out of town will be Pre-recorded, with the tapes released on the regularly scheduled date. Homework will be assigned and due on the normal schedule of Monday 0800 (8:00 am) Pacific time zone, ***each week***.
2. The class is designed as an applied class, with emphasis on applications, although theoretical backgrounds will be covered.
3. The above course outline is more of a goal, than a fact. We will try to cover most of the materials listed above. In past years, we have been able to cover almost all of the listed subjects
4. There are more lectures/workshops, in the above course outline than there are weeks in the Term. Some weeks, we will cover more than one subject.
5. The goal will be to complete the formal portions of the class by the first class meeting, in November, leaving the remaining class sessions for student projects and presentations.
6. ***All*** students will be expected to be present for the Hour Exams. DEN students must make arrangements via the DEN Examination Coordinator for an exam site and proctor. The tests will evaluate your application of the knowledge gained from the lectures, readings, in-class exercises, homework, and review questions. ***There will be more on the tests than you can cover in one hour.*** The individual question/problem weights will be listed. Part of your assignment, will be to manage your time, so as to "do the most damage" to the test, as possible. ***You will be provided with everything that you need (including nomographs), except***:
    a. Your working knowledge of what is to be tested.
    b. Colored pencils.
    c. Straight edges & rulers and/or proportional dividers and rolling rulers.
    d. Protractors and/or rolling rulers.
    e. Hand calculators (No Computers allowed. *The TA will collect all computers at the door and sell them on the street, to finance his/her continuing education*.
7. ***There will be no Final Examination***, as such. My marching orders, from Dr Ershaghi, USC Petroleum Engineering Program Director, were to be able to certify that ALL students who complete the class *CAN DO* Formation Evaluation. The Asset Appraisal Well Project will accomplish that. The class will be divided into teams of 2 – 3 students (decided by lot, with at least on on-campus student and at least one DEN student and English the only common language), with each team assigned a different well to evaluate and report it out to Management. The class will meet, during Finals week, with each team allowed 15 minutes to report their well. ***Each team will "sink or swim" together***. I am convinced that the students will learn more from everyone working on different wells, and listening to each other's presentations, than they would, from studying for a more formal Final Examination.

My job will be to keep everyone engaged, current, and committed to the class goals. Your job will be to ***keep current, and not fall behind***. If we both accomplish our jobs, the class will be interesting and rewarding. Good Luck. I will see you all, either in person or via the Internet, August 27.

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