USC PTE-461: Basic Formation Evaluation

Fall Semester, 2010

ABOUT THE COURSE

PTE-461 is an applied course, teaching skills used by professional Engineers, Geologists, Geophysicists and Petrophysicists, in the Petroleum Industry, on a daily basis. It is based on an in-house training class, developed for Chevron Overseas Petroleum, Incorporated, modified to accommodate the needs of an academic environment. While the content changes, each year, the same general format has been followed for the past six years.

PTE-461 is a hybrid class, in that some students will be n-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 California to New York City.

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 the petroleum industry.

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 and Chemists are also welcome. Students have come from: Afghanistan, Argentina, Canada, China, Columbia, France, Gabon, India, Iran, Korea, Nigeria, Saudi Arabia, Syria, Thailand, and Venezuela, as well as the US.

PTE-461 is also very demanding: for the students, the Teaching Assistants, and the instructor. In fourteen weeks, this class covers the same material covered in twenty weeks, at Stanford. Those students not willing to commit themselves to keeping up with the pace of PTE-461 should consider other classes.

The class begins, with an explanation of what constitutes a petroleum reservoir. Fourteen weeks later the class has divided into teams and using commercial formation evaluation (FE) software to evaluate data from unknown wells and reporting their results to the management of Flank Oil, limited, just as would be done in industry. In between the physical, and chemical foundations of the laboratory, wireline, and measurements while drilling (MWD) measurements utilized in formation evaluation are developed and their practical application examined. All in-class and homework exercises are based on real problems actually faced, by the instructor.

**COURSE OUTLINE**

**Lecture 1: Introduction**
- Class Description and Goals
- The Drilling Well
- What are Well Logs?
- Role of Formation Evaluation/Petrophysics in The Petroleum Industry
- What is Desired and What is Measured
- Who are Petrophysicists and How do They Work
- Well Logs and How They are Acquired
- Uses of Well Logs
- Historical Development
- The Schlumberger Legacy

**Lecture 2: Petroleum Geology Lite**
- Introduction
- Minerals
- Rocks
- Reservoirs
- Origin of Petroleum
- Hydrocarbon Migration
- Petroleum Reservoir Requirements
- Atlas of Reservoir Type Examples
- Bi-Modal Clastic Model

**Lecture 3: Petrophysics**
- Definitions
- Collection, Storage, Preservation, and Preparation of Rock and Fluid Samples for Laboratory Measurements
- Routine Core Analysis
- Maximum Likelihood, or Reduced Major Axis (RMA) Data Fitting Methods
- Special Core Analysis Laboratory (SCAL) Measurements
- Formation Factor and Resistivity Index
- Capillary Pressure and Leverett J-Function
- Elasticity and Elastic Wave Propagation
- Acoustic Porosity Petrophysical Models
- Fluid Measurements
- Effects of Clay Minerals on Flow, Electrical, and Other Physical Properties
- Shaly-Sand Petrophysical Saturation Models

**Lecture 4: Well Logging Environment**
- Introduction
- Wellsite
- Wireline and Measurements While Drilling (MWD) Well Logs
- Borehole Model
- Environmental Effects and Corrections
- Subsurface Temperatures

**Lecture 5: Resistivity Measurements**
- Introduction
- Electrical Measurement Log Curves
- 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. $R_{SP}$ 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_w Estimates
C. R_o Log
D. F_w/F_o Log
E. F_w/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 19: Tough Logging Conditions & Measurements While Drilling  
A. Tough Logging Conditions  
B. Measurements While Drilling  
C. Horizontal Well Applications
READING ASSIGNMENTS

All of the lectures and workshops will have reading assignments. Some will be in he Bassiouni textbook. 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.

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 three different mechanisms:

• Two One-Hour Written Examinations (15% of Final Grade, Each)
• One Fifteen Minute (Fifteen Minutes of Fame) Presentation (15% 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 and Chapters 1–10, in the Bassiouni Text). The Second Hour exam will cover Formation Evaluation Analysis techniques (i.e., Workshops 11–17 & 19).

Fifteen Minutes of Fame

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. Oral presentations and written reports will be how you will be evaluated, in industry, not written examinations.

Asset Appraisal Well Project

The class will be broken up into 2–3 person teams (selected by lot) 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 preparation of short presentation to “Management”.

NOTE:

1. The class will meet every week, in the term, including the September 21st class meeting, which occurs during the Annual SPE ATCE Meetings, as well as any weeks, where the instructor must be out of town.
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 questions/problems 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, 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 one on-campus student and at least one DEN student), with each team assigned a different well from the same field 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, from the same geological environment, 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 24.

Donald G. Hill, Ph.D.
Adjunct Professor of Petrophysics
Petroleum Engineering Program
Mork Family Department of Chemical Engineering,
Materials Science, & Petroleum Engineering
University of Southern California