A GLOBAL HPC-BASED MODEL BUILDING PROCESS FOR HYDROCARBON QUANTIFICATION SERVICES

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This presentation is about using a HPC (high performance computing) based model building process employed for reservoir hydrocarbon quantification purpose at a global scale.

- A brief discussion of services provided by oil field service companies,
- Role of modeling in general,
- Role of modeling and HPC in nuclear well logging area,
- Cased hole services with HPC support,
- Logistics of data transfer,
- Conclusions

SERVICES PROVIDED BY OIL FIELD COMPANIES

- Directional drilling support,
- Hydraulic fracturing,
- Cementing,
- Drilling fluids support,
- Drilling bits,
- Wireline logging services,
- LWD logging services,
- Formation evaluation services,
- Wellbore completion equipment and implementation,
- And others

ROLE OF MODELING in GENERAL

- Modeling/Simulations in Engineering Design Process
  - ANSYS, ABACUS, COMSOL, etc,….

- Modeling/Simulations in Formation Evaluation Work
  - Data Processing, Inversion, Forward Model building,
  - In addition to commercially available software, many codes developed in house,
  - Acoustics,
  - Resistivity,
  - Nuclear,
  - etc.,

ROLE OF MODELING IN WELL LOGGING AND FORMATION EVALUATION

Acoustic Logging Modeling/Simulations

(Mostly forward and some inverse modeling, heavy use of FEM)

$$\nabla^2 P - \frac{\partial^2 P}{c^2 \partial t^2} = F$$

Resistivity Logging Modeling/Simulations

(Forward and inverse modeling , heavy use of FEM, some boundary elements,..)

$$\nabla \cdot \mathbf{D} = \rho_{\mathbf{f}}$$

$$\nabla \cdot \mathbf{B} = 0$$

$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$

$$\nabla \times \mathbf{H} = \mathbf{J}_f + \frac{\partial \mathbf{D}}{\partial t}$$

ROLE OF MODELING IN WELL LOGGING AND FORMATION EVALUATION

Nuclear Logging Modeling/Simulations (Mostly forward modeling)

$$\frac{\partial \Psi_n}{v\,\partial t} + \boldsymbol{\Omega}\cdot\nabla\Psi_n(\boldsymbol{r},E,\boldsymbol{\Omega}) + \Sigma_{n,t}(\boldsymbol{r},E)\Psi_n(\boldsymbol{r},E,\boldsymbol{\Omega}) = \int_{E}^{\infty}\int_{4\pi}\Sigma_n(\boldsymbol{r},E'\to E,\boldsymbol{\Omega}'\to\boldsymbol{\Omega})\Psi_n(\boldsymbol{r},E',\boldsymbol{\Omega}')\,dE'\,d\boldsymbol{\Omega}' + S_n(\boldsymbol{r},E,\boldsymbol{\Omega})$$

$$\boldsymbol{\Omega}\cdot\nabla\Psi_e(\boldsymbol{r},E,\boldsymbol{\Omega}) + \Sigma_{e,t}(\boldsymbol{r},E)\Psi_n(\boldsymbol{r},E,\boldsymbol{\Omega}) = \int_{E}^{\infty}\int_{4\pi}\Sigma_e(\boldsymbol{r},E'\to E,\boldsymbol{\Omega}'\to\boldsymbol{\Omega})\Psi_e(\boldsymbol{r},E',\boldsymbol{\Omega}')\,dE'\,d\boldsymbol{\Omega}' + S_e(\boldsymbol{r},E,\boldsymbol{\Omega})$$

$$\boldsymbol{\Omega}\cdot\nabla\Psi_\gamma(\boldsymbol{r},E,\boldsymbol{\Omega}) + \Sigma_{\gamma,t}(\boldsymbol{r},E)\Psi_\gamma(\boldsymbol{r},E,\boldsymbol{\Omega}) = \int_{E}^{\infty}\int_{4\pi}\Sigma_\gamma(\boldsymbol{r},E'\to E,\boldsymbol{\Omega}'\to\boldsymbol{\Omega})\Psi_\gamma(\boldsymbol{r},E',\boldsymbol{\Omega}')\,dE'\,d\boldsymbol{\Omega}' + S_\gamma(\boldsymbol{r},E,\boldsymbol{\Omega})$$

where

$S_e(\boldsymbol{r},E,\boldsymbol{\Omega}) = f(\Psi_\gamma,\Psi_n)$

$S_\gamma(\boldsymbol{r},E,\boldsymbol{\Omega}) = f(\Psi_n,\Psi_e)$

Boundary and initial conditions are chosen as a function of the problem.

MODELING IN NUCLEAR LOGGING

- Neutron/photon/electron transport can be handled either through deterministic or stochastic methods,
- There are various deterministic codes available for neutron/photon transport. Various approaches based on discrete ordinates, spherical harmonics, etc., are available handling angular dependency. FEM, finite difference are used for spatial discretization. Electron transport is challenging for deterministic computations,
- Energy spectrum of recorded gamma and neutrons are quite important for nuclear well logging problems,
- Deterministic methods don’t provide ‘continuous’ spectra. They usually provide results in multigroup structure that may not be adequate for nuclear well logging practices,
- Multigroup cross sections need to be determined everytime when there is a deterministic calculation. This is not practical,
- Providing geometrical representation of nuclear tools for deterministic computations is not very straightforward either.

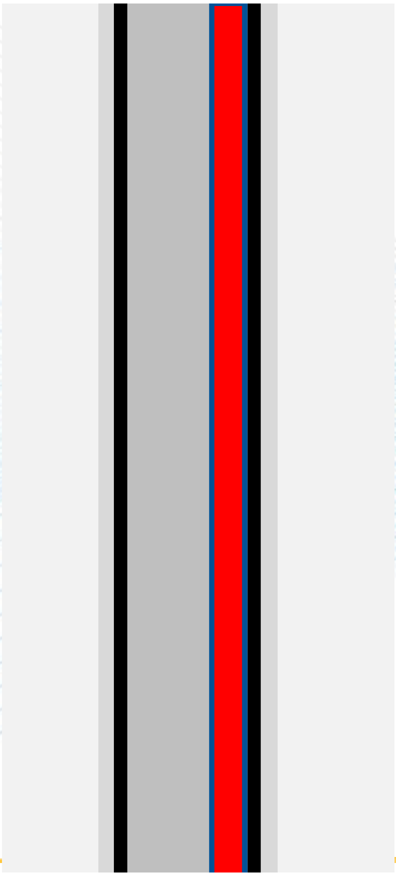
MODELING IN NUCLEAR LOGGING

- Nuclear well logging makes extensive use of Monte Carlo simulations,
- MCNP, Monte Carlo N-Particle, is industry standard in nuclear well logging,
- MCNP code has been under development for more than two decades by Los Alamos National Laboratory and distributed by Oak Ridge National Laboratory Radiation Safety Information Computational Center. It is a general purpose code. Export Control issues puts very stricts restrictions on the distribution of the code,
- Due to general characteristics of the nuclear well logging tools, geometrical representation is relatively easy. ‘Continuous’ cross section data libraries come with the package. All needed is to provide material weight fractions.

MODELING IN NUCLEAR LOGGING

- MCNP can be run either in serial or parallel mode,
- It supports MPI and OpenMP,
- Depending on the problem descriptions, run times can vary from a couple of hours to a couple of weeks.
- Neutrons only transport problems are usually faster. The results in such problems can be obtained within many hours,
- Natural gamma problems can be done relatively fast as well. A typical analog natural gamma problem will be finished within a day or two,
- A gamma-gamma density problem will require variance reduction to be able to obtain results within reasonable time frames,
- Neutron+Neutron induced photon problems require significant computing even with variance reduction techniques. For such problems, we need significant computing to obtain good results.

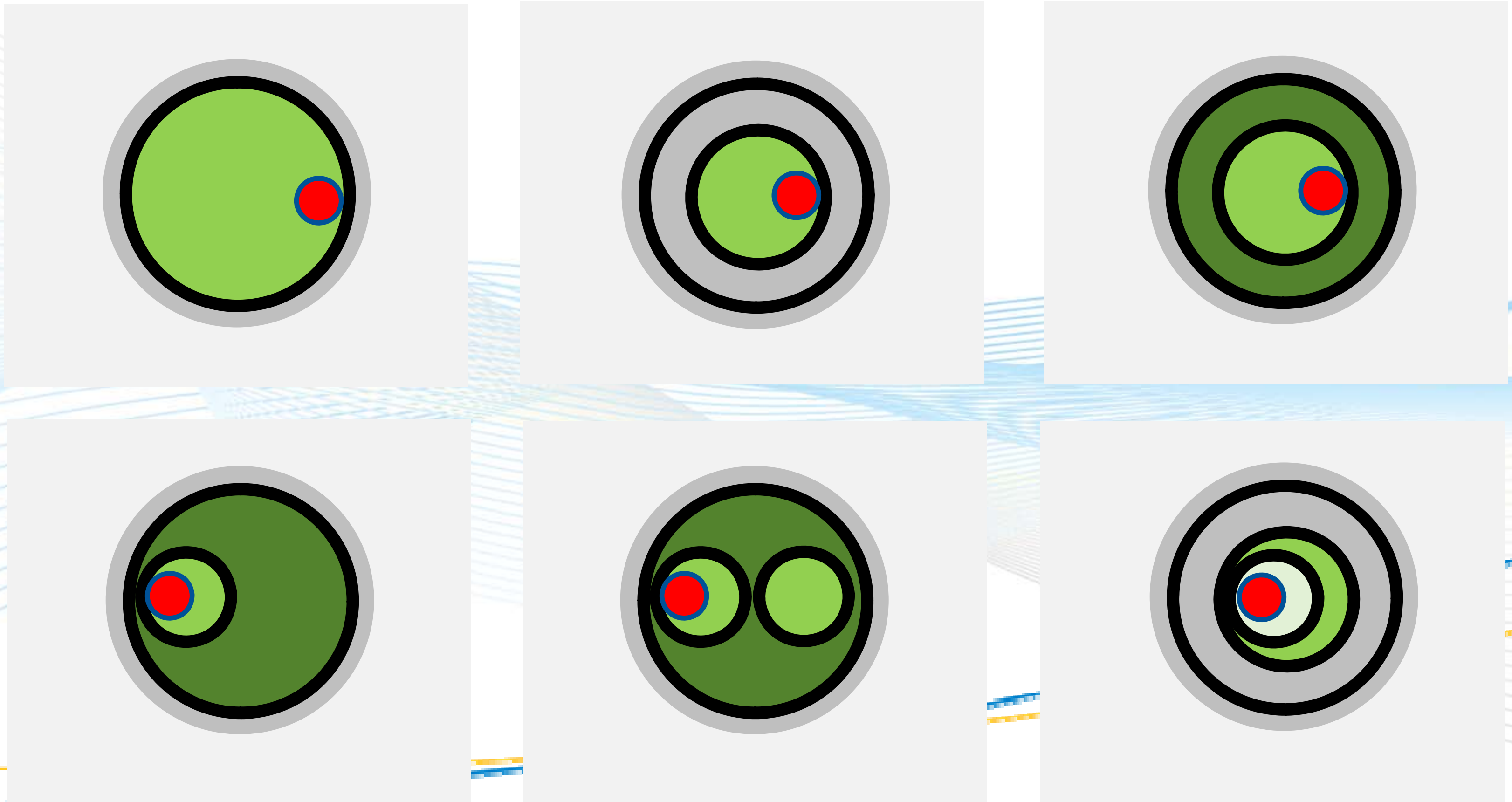
CASED WELL LOGGING



- Due to presence of metallic casing, tubing and cement between the tool and the formation, most of the measurements except the ones using neutrons can not be used in cased hole logging activities,
- Most of cased hole logging services will rely on neutrons emitted by pulse neutron generators and record the photons induced by neutrons in the formation,
- SIGMA, C/O are well known services. BHI GasView service heavily relies on modeling/simulations due to difficulties of characterizing tools for practically infinite number of completion combinations.

CASED WELL LOGGING

Some Completion Cross Section Schematics



CASED WELL LOGGING

- RPM-C Tool,
- 1-11/16” OD tool,
- Driven by a Pulse Neutron Generator,
- 3 Scintillation Detectors,
- GasView measurements (PNC3D)
- SIGMA measurements (PNC2D),
- C/O measurements,
- PNHI measurements,
- Flow measurements using activation.

MEASUREMENT BACKGROUND

- PNC3D mode is a 1kHz measurement,
- In each sequence, pulse neutron generator emits a 60 microsecond long neutron pulse at 14 MeV,
- The detectors are triggered with the pulse and they start to acquire gamma counts,
- Each measurement goes up to 1000 microsecond before another pulse is triggered,
- During the pulse, most of the recorded gammas are gammas emitted through inelastic collisions of fast neutrons and nuclei in the medium,
- Once the pulse is over, there are not fast neutrons in the medium and gammas recorded are from the thermal neutron capture reactions.
- Inelastic collisions are heavily influenced by amount of hydrogen in the medium but not by salinity and other thermal capturers.

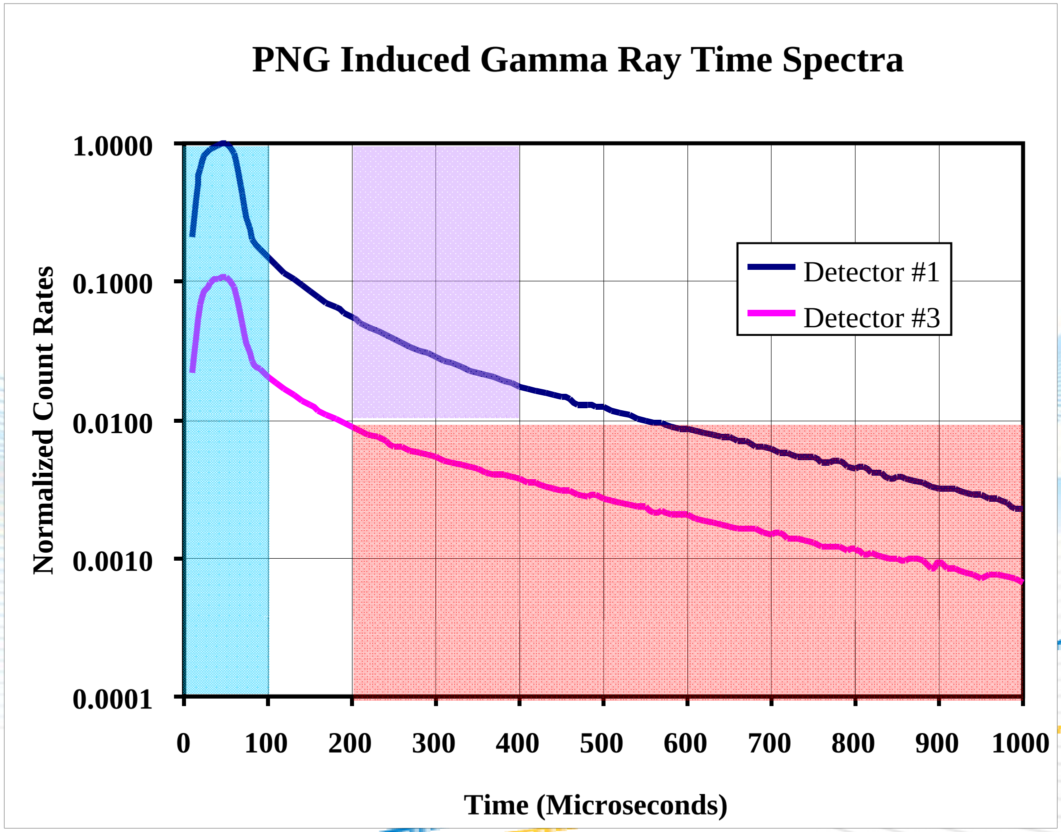
MEASUREMENT BACKGROUND

RIN13

$$R_{13} = \frac{\int_{0}^{100} N_{ss}(t)dt}{\int_{0}^{100} N_{xls}(t)dt} \approx \frac{\sum_{i=1}^{10} N_{i,ss}}{\sum_{i=1}^{10} N_{i,xls}}$$

RATO13

$$R_{capture} = \frac{\int_{200}^{400} N_{ss}(t)dt}{\int_{200}^{1000} N_{xls}(t)dt} \approx \frac{\frac{1}{20}\sum_{i=21}^{40} N_{i,ss}}{\frac{1}{80}\sum_{i=21}^{100} N_{i,xls}}$$

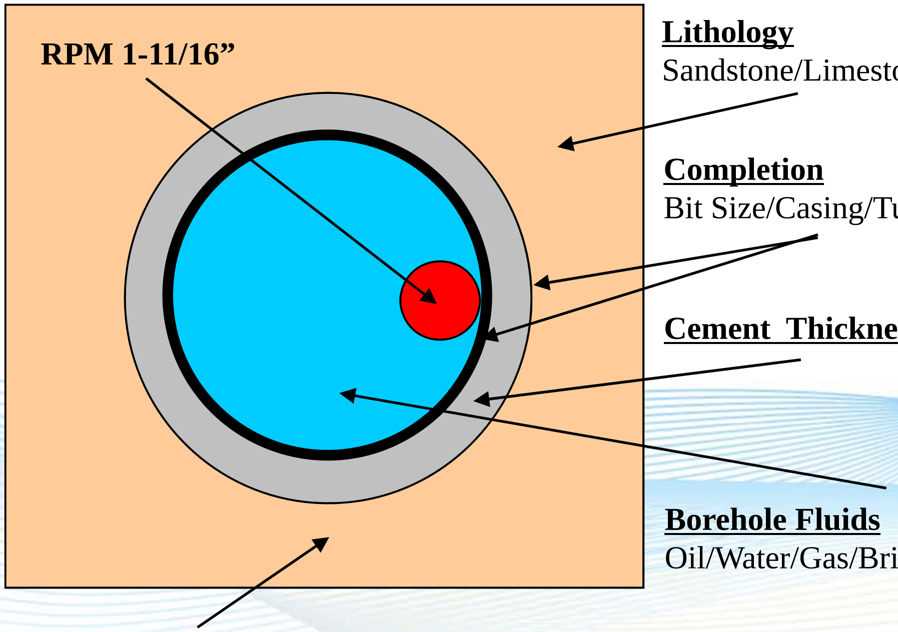


MODELING BACKGROUND

- The purpose of the modeling is to predict RIN13 and RATO13 values for given parameters,
- Completion has a huge impact on RIN13 and RATO13 values. Therefore, any interpretation should be based on values that account for the completion,
- Completion is not homogenous in a given well. Depending on what depth is to be logged, there might be multiple models required for a single logging job,
- For a single model, 36 Monte Carlo runs are required. Each is about one day run on a relatively fast processors. If there are 3 models required for one logging jobs, this would require 108 simultaneous Monte Carlo runs,
- Postprocesing of Monte Carlo runs are usually very fast,
- Since this is revenue generating activity, the model is supplied to the operations within 4 days after the request is received.

MODELING BACKGROUND

- There is a library of existing models,
- New ones are being added on a continuous basis because of unforeseen completion combinations,
- Requires 36 sets of simulations for each model,
- Very computation intensive approach requiring significant computing resources
- Based on a modified MCNP code
- Modeling outcome is dynamic gas envelope (DGE)



RPM 1-11/16”

Lithology
Sandstone/Limestone /Dolomite

Completion
Bit Size/Casing/Tubing Size

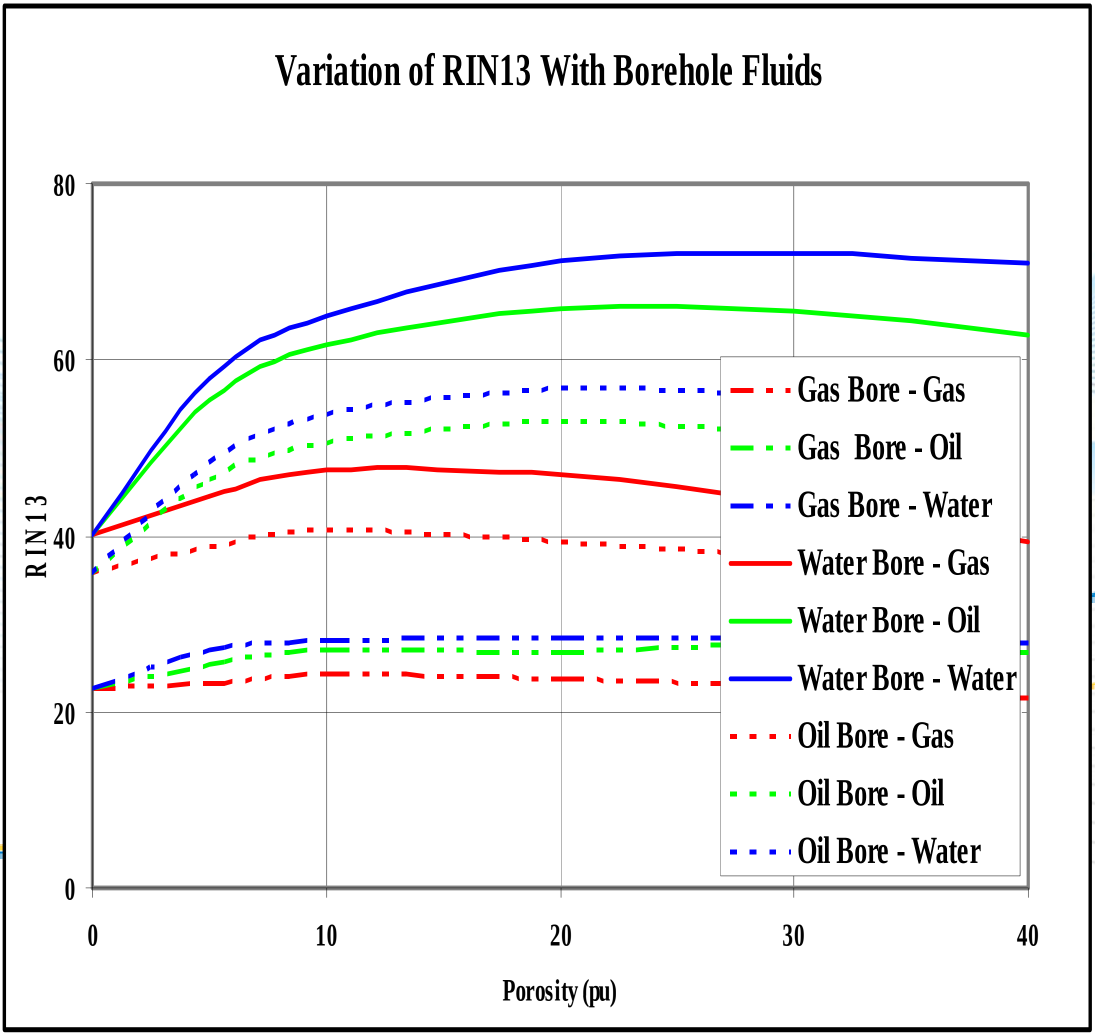
Cement Thickness/Type

Borehole Fluids
Oil/Water/Gas/Brines/FWM/OBM

Formation Fluids
Water salinity/oil density/gas composition and density

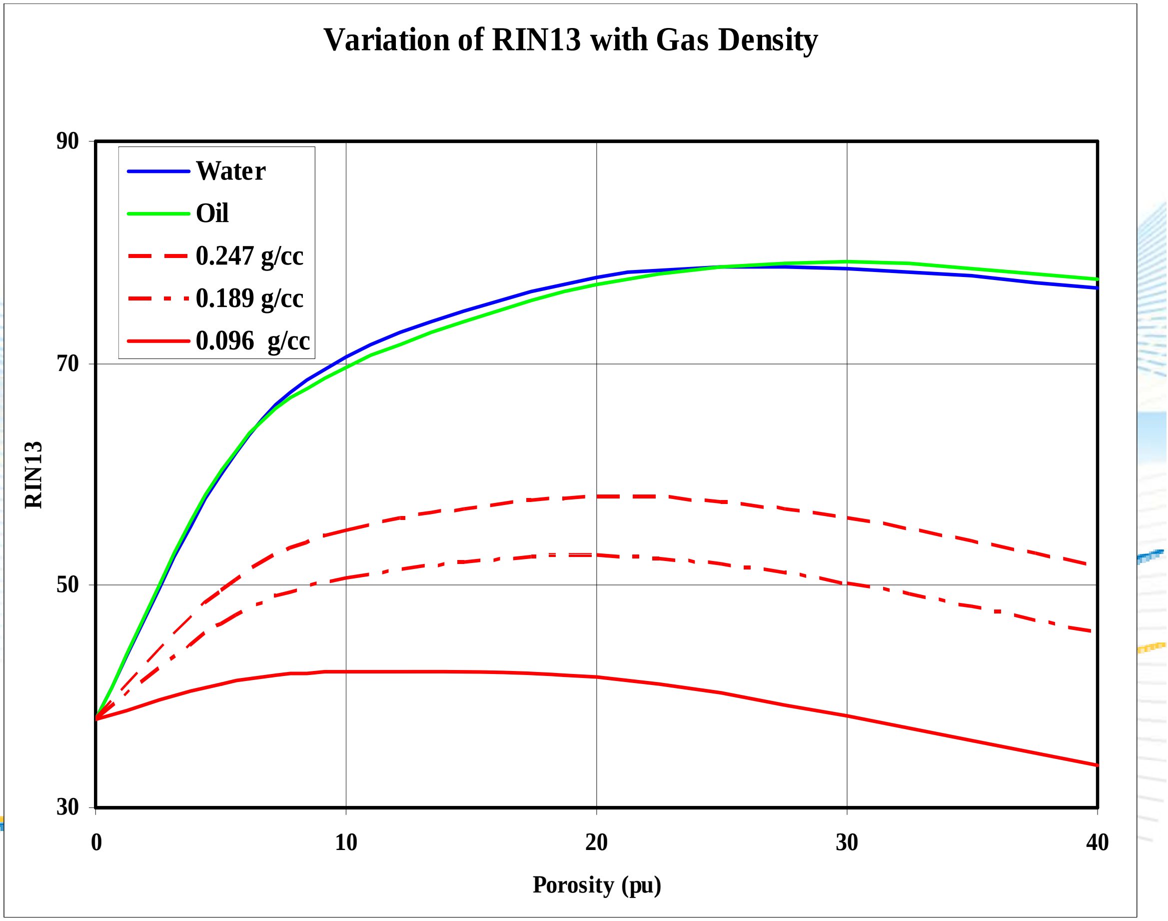
TYPICAL MODELS

- RIN13 is sensitive to borehole fluids,
- The difference between water and oil boreholes is relatively small,
- The gas borehole response is low and the dynamic range is small as well,
- This is due to the decreased hydrogen content in borehole. Fast neutrons travel farther and causes a larger signal at extra far detector,
- Gas borehole cases require other approaches rather than RIN13
- This plot requires 108 Monte Carlo runs



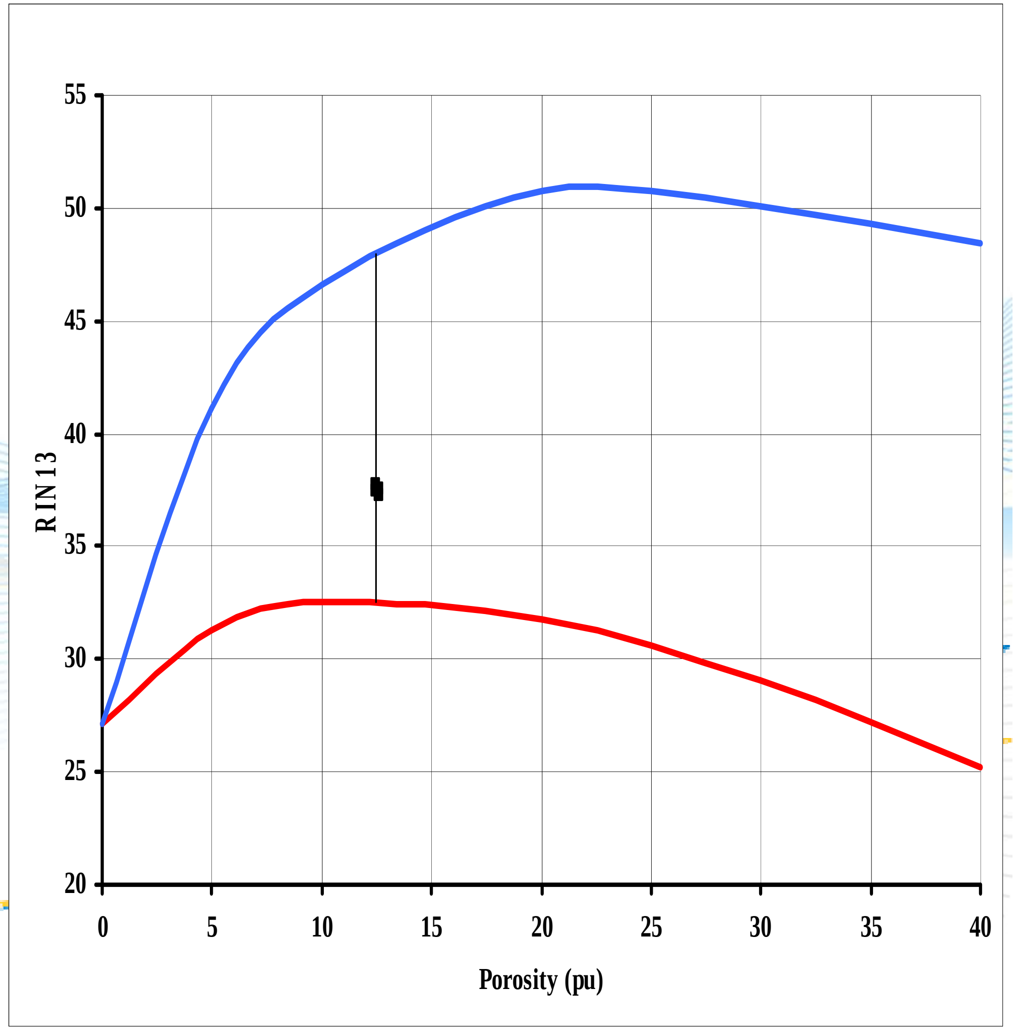
TYPICAL MODELS

- Gas densities ranging from 2000 to 6000 psi,
- 8.5″ borehole,
- 7″ casing,
- 0.8 g/cc formation oil,
- 1.03 g/cc formation water,
- RIN13 very sensitive to gas pressure (density)
- Formation hydrogen content has a huge impact on results
- This plot requires 60 Monte Carlo runs

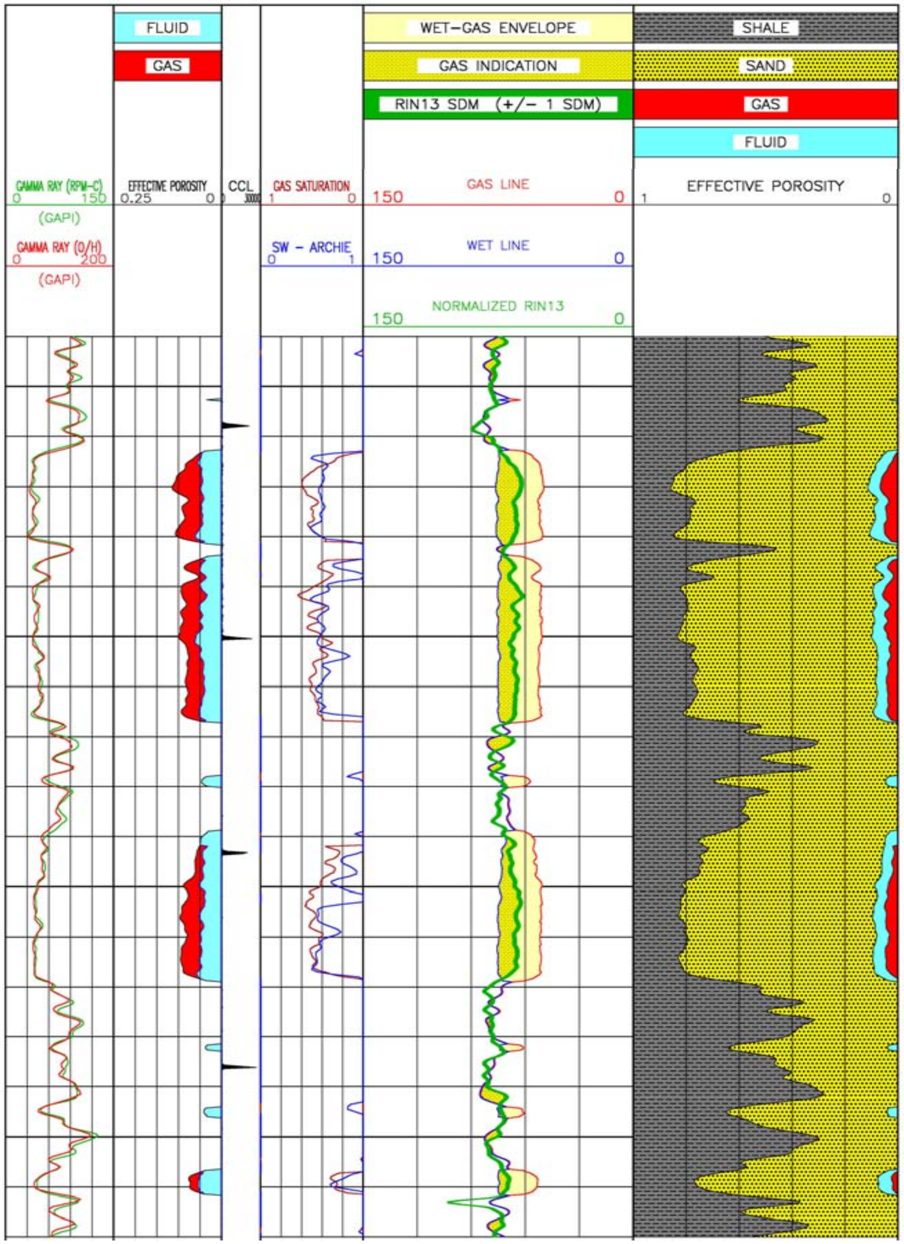


INTERPRETATION ISSUES

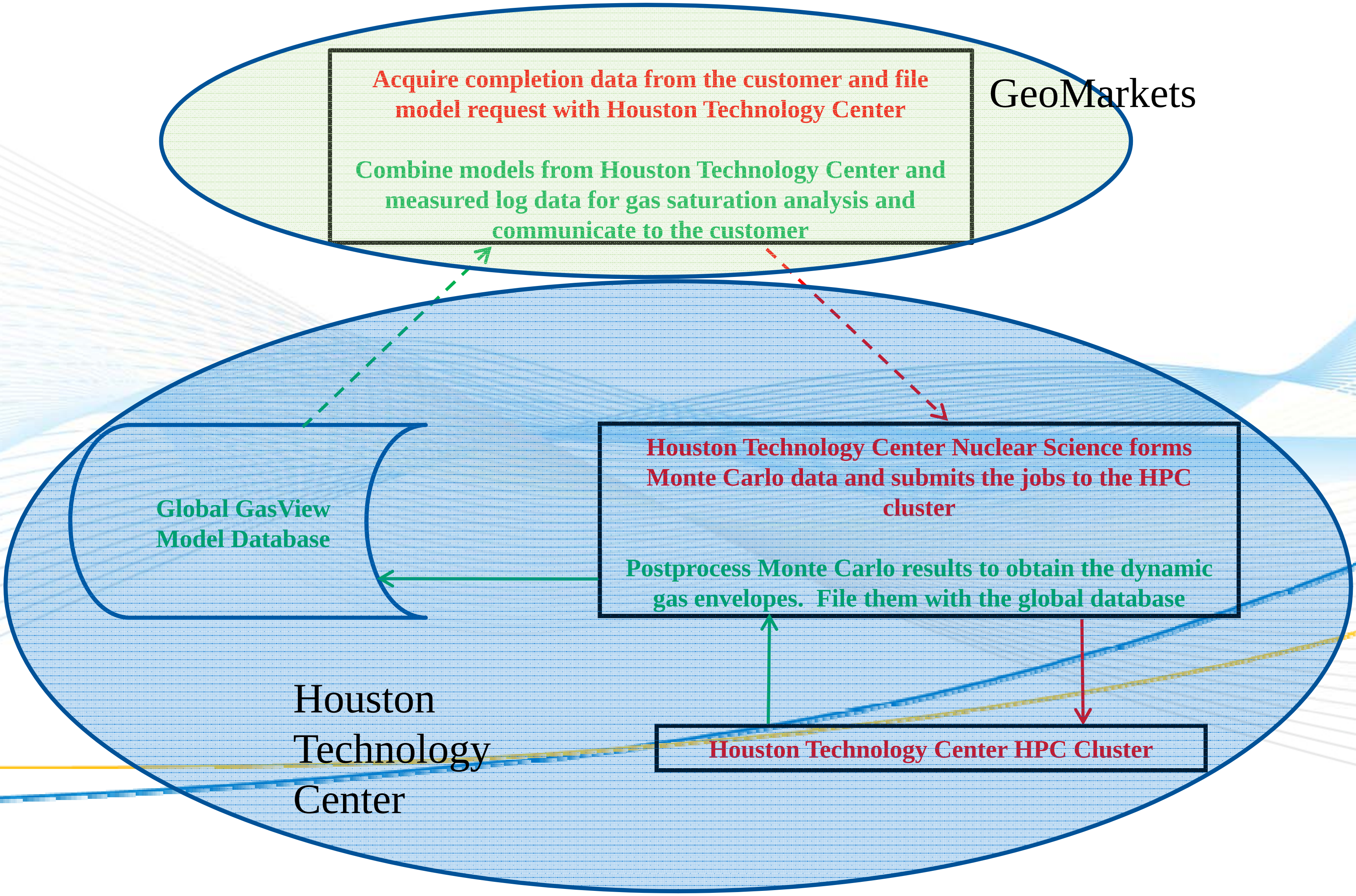
- There is usually a normalization step with the data at the first step,
- Once the normalization is done, there will be a step for clay correction,
- Once the first two steps are completed, RIN13 data can be used for gas saturation quantification,
- RIN13 point is to fall between gas line and wet line,
- Transition from gas line to wet line is not linear and some correlations are used to interpolate between gas lines and wet lines.



SAMPLE LOG


FLUID
GAS
WET–GAS ENVELOPE
GAS INDICATION
RIN13 SDM (+/– 1 SDM)
SHALE
SAND
GAS
FLUID
GAMMA RAY (RPM–C)
0
150
(GAPI)
GAMMA RAY (O/H)
0
200
(GAPI)
EFFECTIVE POROSITY
0.25
0
CCL
0
30000
GAS SATURATION
1
0
SW – ARCHIE
0
1
GAS LINE
150
0
WET LINE
150
0
NORMALIZED RIN13
150
0
EFFECTIVE POROSITY
1
0

DATA LOGISTICS and PROCESS



GeoMarkets

Acquire completion data from the customer and file model request with Houston Technology Center

Combine models from Houston Technology Center and measured log data for gas saturation analysis and communicate to the customer

Houston Technology Center

Global GasView Model Database

Houston Technology Center Nuclear Science forms Monte Carlo data and submits the jobs to the HPC cluster

Postprocess Monte Carlo results to obtain the dynamic gas envelopes. File them with the global database

Houston Technology Center HPC Cluster

DATA LOGISTICS and PROCESS

Typical model request form automatically delivered to the HTC once filled out by the analysts in the Geomarkets

- BA_RPM_Model

Header:
Name: xxxxxx
Comment: Gravel Pack with 0.35 porosity and water 1 g/cc fluid. Screen ID 5.5, OD 6.5'‘
Formation Gas Density: 0.1
Gas Composition: CH4
Formation Oil Density Units: g/cc
Formation Oil Density: 0.8
Formation Water Density: 1
Formation Water Density Units:
Borehole Fluid Density Units: g/cc
Borehole Fluid Density: 1
Tubing Fluid Density Units: g/cc
Tubing Fluid Density: 1
Tubing: 2.875
Casing: 9.625
Bit Size: 12.25
Mineralogy: Sandstone
Well Name:
Products: Co
Region: MEAP
Cost Center:
Submitted by (Email):
xxxxxxx@bakerhughes.com

DATA LOGISTICS and PROCESS

Global GasView Database

ID	Bit Size (in.)	Lithology	Casing OD	Tubing OD	Tubing Fuid Density (g/cc)	Fluid Density - Annulus	Formation Oil Density (g/cc)	Formation Water Density (g/cc)	Formation Gas Density (g/cc)	GasResponse
1576	7.875	Dolomite	5.500		0.999	1.917	0.80	1.000	0.020	Completed
1575	7.875	Limestone	5.500		0.999	1.917	0.80	1.000	0.020	Completed
1574	7.875	Sandstone	5.500		0.999	0.020	0.80	1.000	0.020	Completed
1573	7.875	Limestone	5.500		0.999	0.020	0.80	1.000	0.020	Completed
1572	7.875	Sandstone	5.500		0.999	1.917	0.80	1.000	0.020	Completed
1571	7.875	Dolomite	5.500		0.999	0.020	0.80	1.000	0.020	Completed
1570	7.875	Sandstone	5.500		0.999	0.020	0.80	1.000	0.020	Completed
1569	7.875	Sandstone	5.500		0.999	1.917	0.80	1.000	0.020	Completed
1568	6.750	Sandstone	4.500		0.050	1.917	0.80	1.000	0.150	Completed
1567	8.500	Sandstone	7.000	3.500	1.300	1.300	0.80	1.000	0.160	Completed
1566	6.750	Sandstone	3.500		2.014	1.917	0.80	1.000	0.250	Completed
1565	6.750	Sandstone	3.500		2.014	1.917	0.80	1.000	0.200	Completed
1564	8.500	Sandstone	7.000	3.900	1.300	1.300	0.80	1.000	0.160	Completed
1563	8.500	Limestone	7.000		0.950	1.917	0.80	1.116	0.200	Completed
1562	12.250	Sandstone	9.625		1.030	1.917	0.83	1.022	0.160	Completed
1561	12.250	Sandstone	9.625		1.030	1.917	0.81	1.021	0.160	Completed
1560	12.250	Sandstone	9.625		1.000	1.917	0.66	1.000	0.120	Completed
1559	12.250	Sandstone	9.625		1.000	1.917	0.66	1.000	0.120	Completed
1558	12.250	Sandstone	9.625		1.000	1.917	0.66	1.000	0.120	Completed
1557	7.875	Dolomite	5.500		0.999	1.917	0.80	1.000	0.020	Completed
1556	12.250	Limestone	9.625 & 7.000	3.500	1.200	1.200	0.80	1.135	0.180	Completed

CONCLUSIONS

- The process described here is a unique process where the model based synthetic data is used with measured log values to extract gas saturation values. It opens up a new venue where quantification of certain parameters can be made by using not only measured parameters but in combination of measured logs with the synthetic data,
- The models built are very computing intensive. A typical model requires about 700-1000 CPU hrs,
- The service requires in the range of 200,000 – 300,000 CPU hours in a year,
- Without the availability of HPC resources, such a service can not be provided to the oil and gas industry,
- Although it is clear that combining synthetic data and measured data provides a mean to obtain quantification, it is very clear that such goals can be realized through availability of HPC resources and HPC skills.