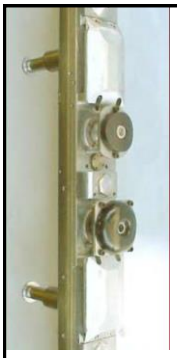


Formation Pressure Testers, Back to Basics.

A review of the acquisition, quality control and use of formation pressures.

Mike Millar

LPS Seminar - Everything Formation Testing
Thursday 14th December 2017

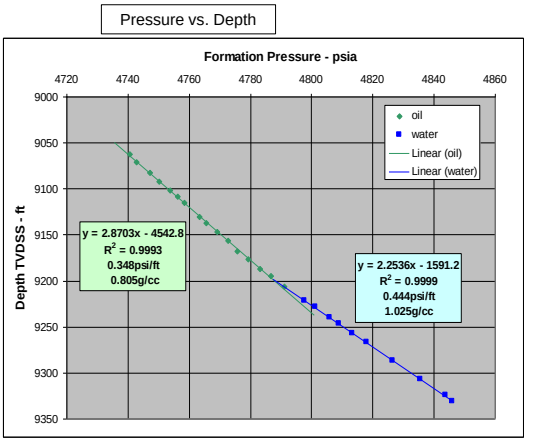
Formation Pressure Testers - Back to Basics.

A review of the acquisition, quality control and use of formation pressures.

Outline;

- What's so great about Formation Pressure Testers (FPTs) ?
- What happens when we drill a well?
- Some thoughts on planning FPT acquisition.
- How do FPTs work and where do the pressures come from ?
- FPTs - how do we get the pressures ?
- How do we know the formation pressures are okay ?
- Summary

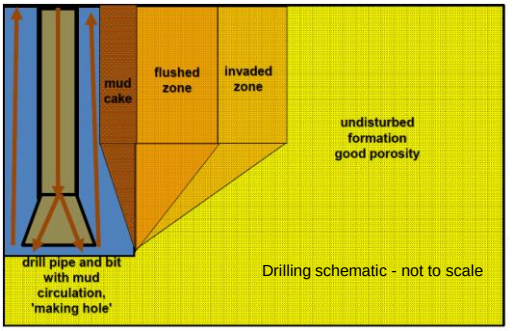
What's so Great About FPTs ?

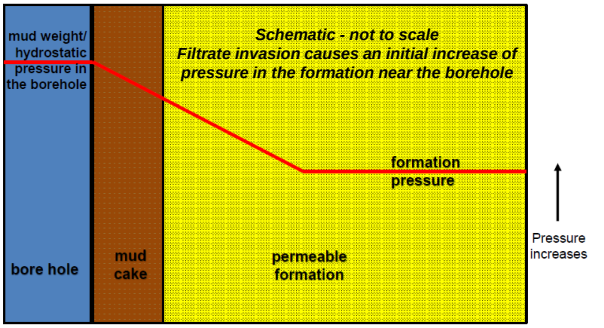


- Formation pressures at specific depths;
  - Quartz and/or Strain gauges
  - absolute or gauge pressure
  - *pretest is short hand for pressure test*
- Temperature at specific depths;
  - gauge (but close to formation temperature).
- Pressure gradients to establish;
  - fluid density and fluid levels
- Permeability estimate (mobility – mD/cp);
  - indication of reservoir quality
- Fluid Samples;
  - identify fluid types
  - PVT Laboratory quality samples are possible
  - formation fluid contaminants possible (Hg, H_2S, CO_2, etc)
- Can be run on wireline (EWL) and on LWD.
- Generally open-hole, but cased hole options available.

What happens when we drill a well ?

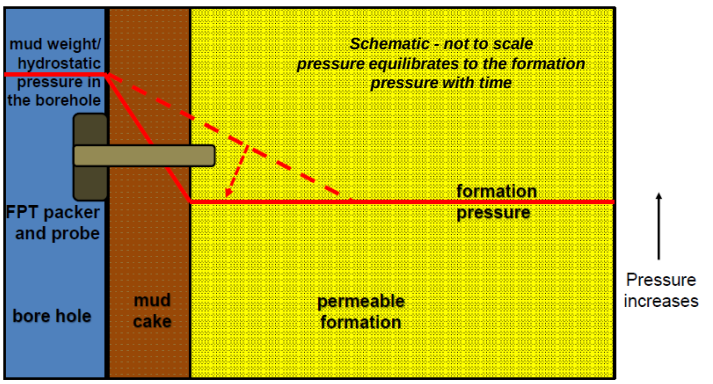
• Drilling changes the pressure and temperature of the rocks and fluids at and near the borehole wall.
• All borehole measurements are affected to some extent by drilling mechanics and the drilling fluid.
• Drilling fluid (mud) has a number of roles in the drilling process, one of which is well control.
• To maintain well control, mud pressure (weight) is usually higher than the formation pressure.
• Mud filtrate invades the rock pores near the well, displacing the some or all of the native fluids.
• Filtrate invasion causes an initial increase of pressure in the formation near the borehole.
• Solids in the invading mud should form a mud cake on the borehole wall, this is designed to stop further invasion.





What happens when we drill a well ?

- Filtrate invasion causes an initial increase of pressure in the formation near the borehole, but this pressure equilibrates to the formation pressure with time - if the formation has some permeability and a good mud cake has built-up to stop further invasion.
- We measure the weight (pressure) of the fluid columns in the formation and in the borehole (mud weight aka hydrostatic pressure).
- In the formation it is weight of the continuous fluid phase that we measure.



Some Thoughts on Planning FPT acquisition

- What are the well objectives, why are we running an FPT ?:
  - Formation pressures - individual and/or gradients, and/or
  - Fluid samples - fluid identification and/or PVT Laboratory quality
- What is the borehole environment ?
  - Temperatures and pressures - tools operating limits.
  - Hole size, shape and inclination can all impact probe/packer selection.
  - Mud issues; big overbalance can increase sticking risk, and solids may cause probe plugging, or may be abrasive and cause damage to the packer or seals etc,
- Are there any potential issues with the expected target formation(s) ?
  - Unconsolidated / friable or low permeability and/or fractured
  - H_2S
- Plan optimum tool-string and running strategy - use service company expertise
  - Conveyancing - EWL, LWD ?
  - Sticking and tension modelling required - involve well engineering in planning
  - Probe/packer choice

Plan for safe operations and don't compromise on safety

Formation Pressure Testers - how do they work ?

- the tools usually consist of;
  - a probe and packer on a retractable pad
  - retractable backup arms
  - a pretest chamber (0.1 to 50cc)
  - gauges to measure pressure and temperature
  - pumps, flowlines and sample chambers
  - as well as conveyancing, power, communications and controls

Formation Pressure Testers - how do they work ?

Pressure gauges

- Pressure gauges operate by converting a pressure change into a mechanical displacement, or deformation.
- This deformation is then converted into an electrical signal that is processed by the measuring system.
- Temperature must be known accurately for the signal to be converted into pressure. So a temperature sensor is usually included within the gauge

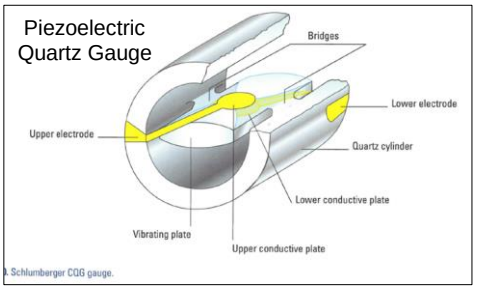
	Accuracy	Resolution	Range
Logging speed	Stationary	Stationary	Stationary
Strain gauge†	±10 psi [±68,947 Pa] ±20 psi [±137,895 Pa]	0.1 psi [689 Pa] 0.2 psi [1,379 Pa]	0 to 10,000 psi [0 to 69 MPa] 0 to 20,000 psi [0 to 138 MPa]
CQG gauge‡	±(2 psi [13,789 Pa] + 0.01% of reading)§ ±(4.0 psi [27,579 Pa] + 0.012% of reading)§	0.01 psi [69 Pa] 0.01 psi [69 Pa]	750 to 15,000 psi [5 to 103 MPa] 0 to 25,000 psi [0 to 172 MPa]
Resistivity	±5% of reading	0.001 ohm.m	0.01 to 20 ohm.m
Flowline temperature	±1.0 degF [±0.5 degC]	1.0 degF [0.5 degC]	–67 to 392 degF [–55 to 200 degC]

† 30,000-psi [207-MPa] strain gauge available on request.
‡ There are several versions of the CQG gauge. The CQG-C and CQG-G gauges are rated to 15,000 psi [103 MPa] and 350 degF [177 degC]. The HCQG-A gauge is rated to 25,000 psi [172 MPa] and 350 degF. A 30,000-psi [207-MPa] quartz gauge is available on request.
§ The 2- and 4-psi accuracy claims include calibration fitting error, hysteresis, repeatability, and some allowance for sensor aging; the corresponding percentages of the pressure readings account for the incertitude of the calibration equipment.

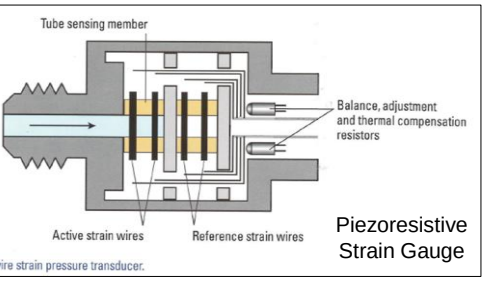
some typical gauge operating limits

Maximum drawdown	8 kpsi (55 MPa)
Range	Quartz gauge: 0 to 12.5 kpsi (0 to 86 MPa) Strain gauge: 0 to 10.0 kpsi (0 to 69 MPa)
Accuracy	Quartz gauge: ±3.2 psi + 0.01% (±22 kPa + 0.01%) Strain gauge: ±15 psi (±104 kPa)

Piezoelectric Quartz Gauge



A. Schlumberger CQG gauge.



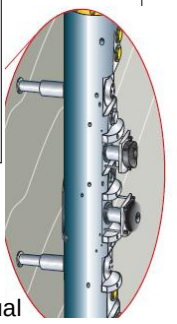
Piezoresistive Strain Gauge

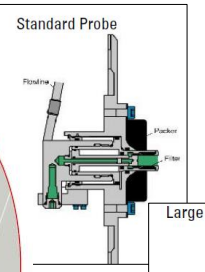
B. Bonded wire strain pressure transducer.

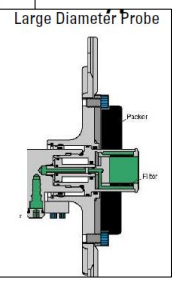
Formation Pressure Testers - how do they work ?

Packers and Probes

- The packer is set against the borehole wall, sealing the probe from the borehole/drilling fluid.
- The probe connects the tool to the formation.
- Different packer and probe designs to address different reservoir conditions.


Dual probe/packer

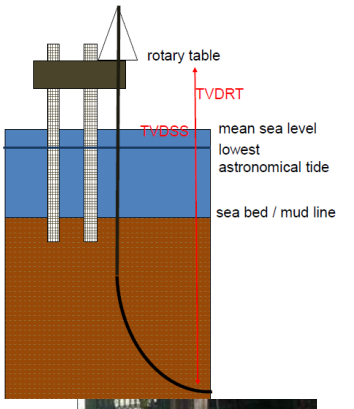


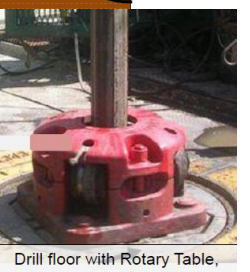


Where do the pressures actually come from ?
- some thoughts on depth measurements

- **Measured Depth - MD**
  - Measure point;
    - Drill-floor (DF), Rotary-table (RT) or Kelly-bushing (KB)
  - Datum - Elevation above:
    - Mean sea-level, Lowest astronomical tide, Ground level, Mud line

- **True vertical depth - TVD; (inclined boreholes)**
  - datum reference, DF, RT, KB, SS (Subsea, but MSL or LAT ?)
  - Inclination - from the vertical
  - Azimuth - well direction relative to North (but which North - True, Grid, or Magnetic?)
  - Survey accuracy
    - Inclination +/- 0.1 deg
    - Azimuth +/- 1.0 deg




Drill floor with Rotary Table, Kelly and Kelly bushing

Where do the pressures actually come from ?
- some more thoughts on depth measurements


Wireline depth measurement wheels

- **Logger's Depth**
  - Wireline accuracy of +/- 0.5ft per 1000ft in ideal circumstances

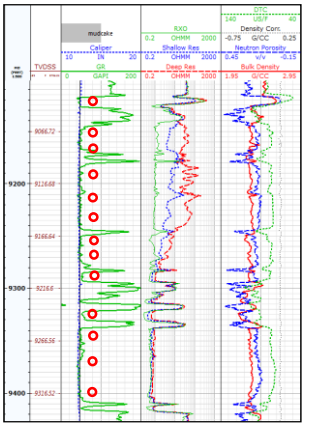
- **Driller's depth**
  - Generally accepted standard for accuracy of Driller's Depth is +/- 2 ft per 1000ft
  - it is the total length of all drill pipe and bottom-hole assembly lowered into the borehole
  - Drill-pipe tension, compression and buoyancy effects can cause errors in the depth

- **LWD data is recorded in time, which is tied to Driller's Depth**
  - Memory data is linked to depth using synchronized clocks
  - Rapid changes in ROP and missed intervals can cause errors in the depth

- **Key point - there is always some uncertainty in depth measurements.**

FPTs - how do we get the pressures ?

- **Pressure tests (pretest) - operating basics**
  - Plan where best to take pretests;
    - good borehole
    - potentially permeable formation
    - enough pretests to define fluid gradients or expected changes in pressures
  - RIH
  - Depth alignment;
    - FPT may be run on a different logging pass to other open-hole logs, so depth alignment is critical
    - Use GR Correlation pass (more than one if required), to make sure the FPT is on-depth with previous logs, so we know that the pretests are being taken where you want them to be taken.

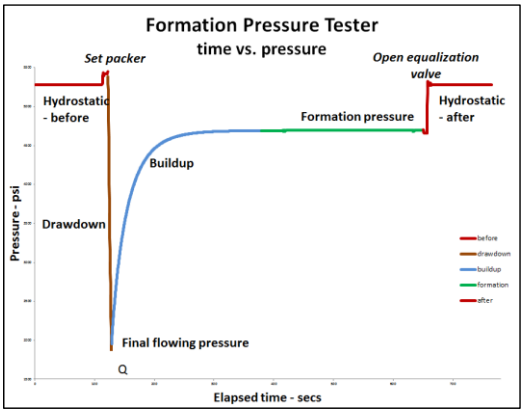


  - and then prepare to set the tool to take your pretest...

FPTs - how do we get the pressures ?

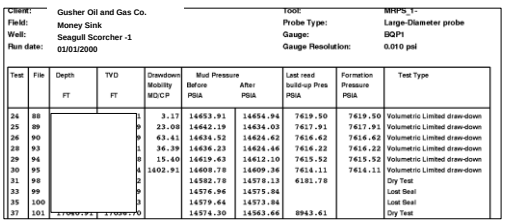
- **Pressure tests - operating basics**

- Taking a pretest, at the predetermined depth;
- The hydrostatic - before pressure is measured.
- The packer is set against the borehole wall, sealing it from the borehole/drilling fluid.
- The probe is pushed through the mudcake into the formation.
- A small volume of fluid is withdrawn (0.1cc to 50cc) by the pretest chamber, causing a pressure drop (drawdown).
- Pressure is then allowed to build-up and it will stabilise at the formation pressure if the formation is permeable.
- The probe is withdrawn and the hydrostatic - after pressure is measured.
- The tool measures these pressure changes as a function of time.
- The draw-down can be used to estimate formation mobility, where drawdown is the difference between final flowing pressure and formation pressure.



FPT Quality Control - How do we know the formation pressures are okay ?

- You should get properly tabulated data;
- Data - File number, depths (MD and TVD and their reference), Hydrostatic (mud) pressures (before and after), Formation pressure (if valid), Temperature, Mobility, Comments.
- record the 'failures' too, it is all useful information;
  - seal failures may indicate unconsolidated sand or tight formation (no mud cake)
  - tight tests may indicate low permeability formation
- You should get a Field Print
  - to investigation of any apparent issues.



Client: Gusher Oil and Gas Co.
Field: Money Sink
Well: Seagull Scorcher -1
Run date: 01/01/2000
Tool: MRPS_1-
Probe Type: Large-Diameter probe
Gauge: BQPI
Gauge Resolution: 0.010 psi

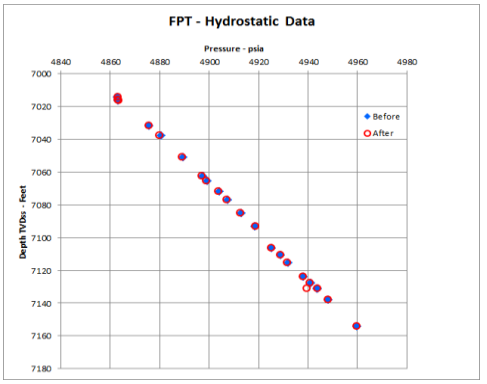
Test	File	Depth FT	TVD FT	Drawdown Mobility MD/CP	Mud Pressure Before PSIA	Mud Pressure After PSIA	Last read build-up Pres PSIA	Formation Pressure PSIA	Test Type
24	88			3.17	14653.91	14654.94	7619.50	7619.50	Volumetric Limited draw-down
25	89			23.08	14642.19	14634.03	7617.91	7617.91	Volumetric Limited draw-down
26	90			63.41	14634.52	14624.62	7616.62	7616.62	Volumetric Limited draw-down
28	93			36.39	14636.23	14624.46	7616.22	7616.22	Volumetric Limited draw-down
29	94			15.40	14619.63	14612.10	7615.52	7615.52	Volumetric Limited draw-down
30	95			1402.91	14608.78	14609.36	7614.11	7614.11	Volumetric Limited draw-down
31	98				14582.78	14578.13	6181.78		Dry Test
33	99				14576.96	14575.84			Lost Seal
35	100				14579.64	14573.84			Lost Seal
37	101				14574.30	14563.66	8943.61		Dry Test

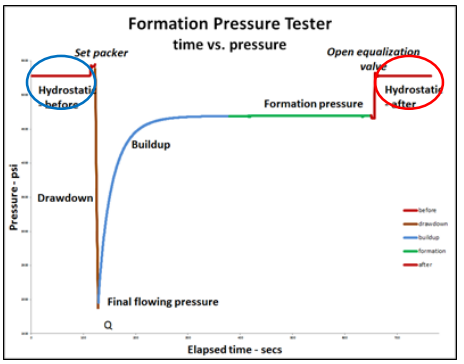
Example FPT tables, from field prints and wellsite work sheet

Test	File	Depths (ft) MDBRT	TVDBRT	TVDSS	Times Start	Duration	Finish	Pressures (psia) Hydrostatic Strain	Quartz	ppg	Formation Strain	Quartz	ppg	Hydrostatic Strain	Quartz	ppg	Zone	Mobility Kdd md	Mobility FRA mD/cP	Temp DegF	DD cc	Comments
1	2				14:05	00:08	14:13		5546.2	11.58					5544.5	11.58	2			194.2	10.0	10cc (fast) ; Tight.
2	3				14:20	05:15	19:35		5546.4	11.58		4766.9	9.95		5543.2	11.57	2	546.0	598.1	194.4	15.0	5cc (med); 10cc (fast). Good
3	4				19:40	04:50	00:30		5555.7	11.58		4773.3	9.95		5550.8	11.57	2	764.9	881.9	197.5	20.0	10cc (fast) ; 10cc (fast). Good
4	6				00:55	06:37	07:32		5577.5	11.58		4783.4	9.94		5573.0	11.58	2	217.3	203.0	198.4	20.0	10cc (fast) ; 10cc (fast). Good
5	8				07:45	03:15	11:00		5596.4	11.59		4793.9	9.93		5600.7	11.60	3	580.2	643.8	199.7	20.0	10cc (fast) ; 10cc (fast). Good
6	10				11:35	03:33	15:08		5682.2	11.60		4855.8	9.91		5684.5	11.60	3	505.4	455.8	202.0	20.0	10cc (fast) ; 10cc (fast). Good

FPT Quality Control

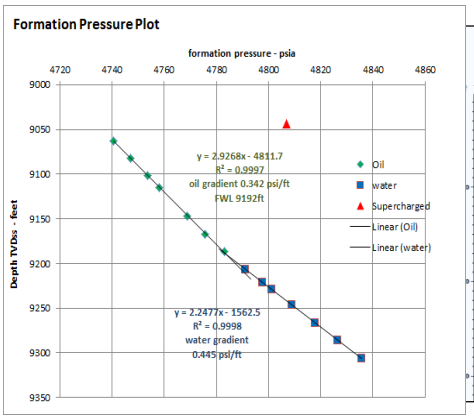
- Check the Before and After Hydrostatic pressures
  - are they the same within gauge accuracy *(ie +/- 2psi for Quartz gauge*)
  - shows that the gauges are working and temperature is stable
- Plot the Before and After Hydrostatic pressures against depth (TVDSS)
  - are the gradients consistent with the mud weight ?
  - confirms that the gauges are reading accurately.

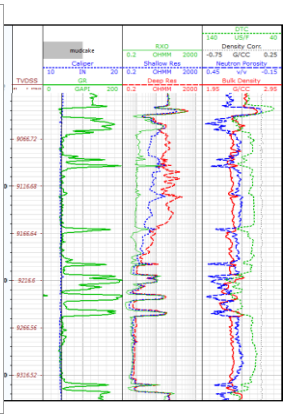


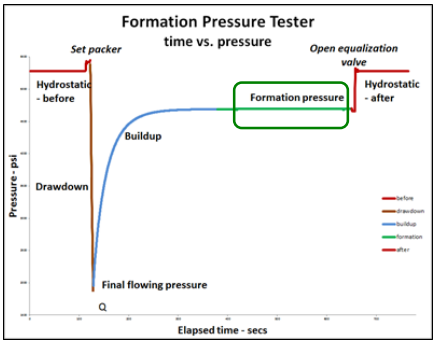


FPT Quality Control

- Plot the formation pressures against depth (TVDSS) and check that they make sense when compared to :
  - all the other borehole data, such as apparently permeable formation
  - the formation fluid types and any observed fluid contacts
    - fluid gradients are functions of the fluids' density
  - the formation pressure is within the expected range, and is consistent with off-set wells







FPT Quality Control

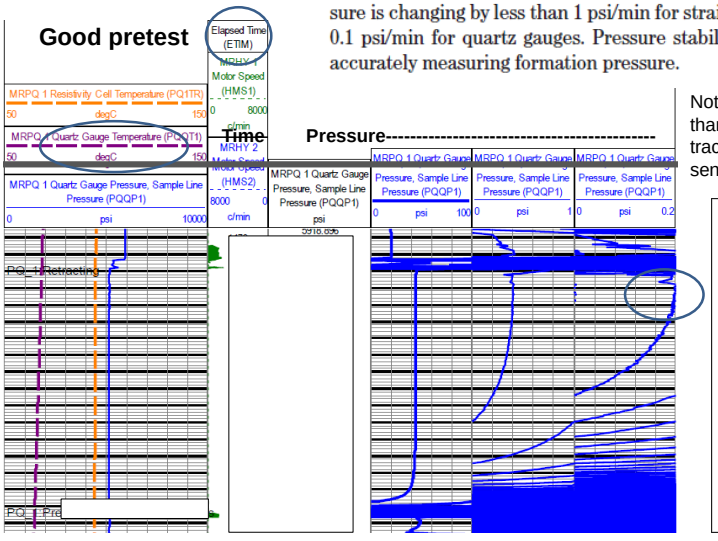
- **Some Pretest Definitions**;
  - **Normal Test** - Pressure builds to formation pressure and is stable. *Valid formation pressure*
  - **Dry Test** - Large drawdown and slow build up. *Does not give valid formation pressure.*
  - **Tight Test** - big drawdown, little or no build up (extreme version of the Dry Test). *Does not give valid formation pressure.*
  - **Lost Seal or Seal Failure** - Packer seal fails – pressure builds back to hydrostatic. *Does not give valid formation pressure.*
  - **Supercharged** - when the overbalance of mud pressure into the formation has not dissipated from the region sampled by the FPT by the time that the FPT takes its pressure. *Does not give valid formation pressure*
  - **Probe or flow line plugging**, by fine grain material from the mud solids or from the formation being sampled. *Does not give valid formation pressure*

17

FPT Quality Control

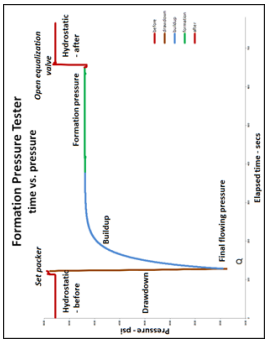
Check the field print

- Good Test - stable formation pressure



- Formation pressure is normally recorded until the measured pressure is changing by less than 1 psi/min for strain gauges or less than 0.1 psi/min for quartz gauges. Pressure stabilization is critical for accurately measuring formation pressure.

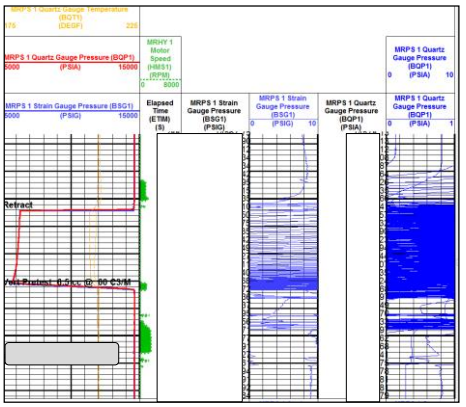
Note that the pressure appears in more than one track, and that each of these tracks has a different scale, showing more sensitivity as we move towards the right

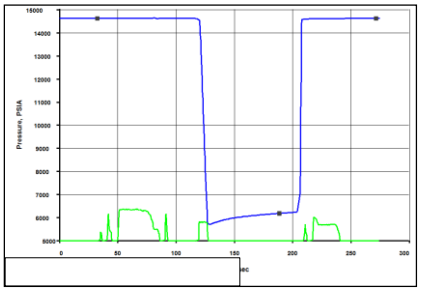


FPT Quality Control

Dry Test

- Big draw-down, slow build-up, not stable
- can be caused by low permeability formation or
- can be caused by big and/or sudden drawdown causing fluid phase separation and relative permeability barriers to flow,
- or thick mud cake, or bad formation damage
- Does not give valid formation pressure

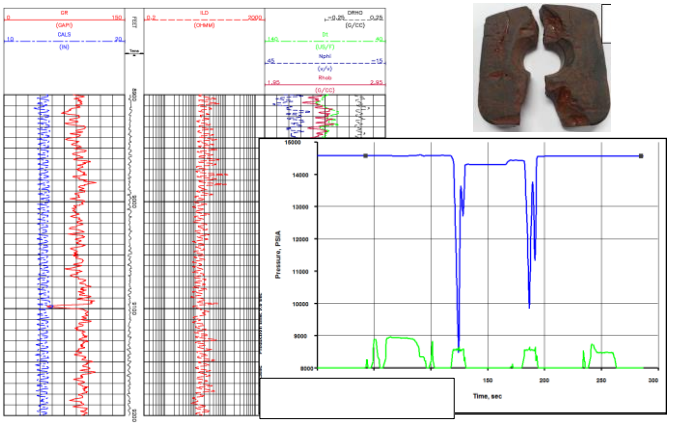


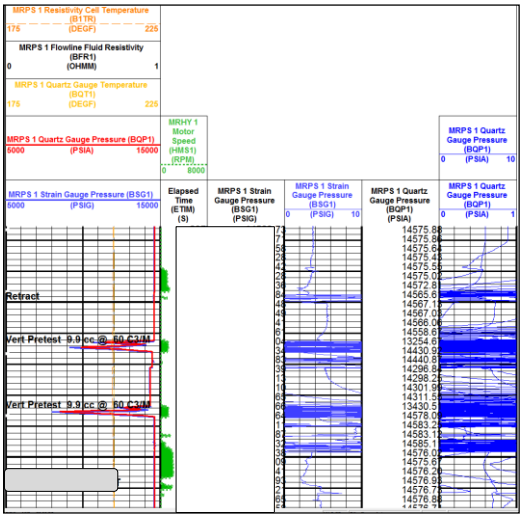


FPT Quality Control

Seal failure

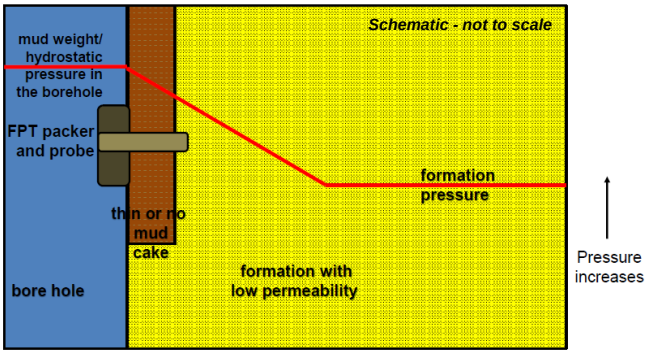
- damaged packer
- little or no mud cake
- rugose or riffled borehole
- Does not give valid formation pressure





FPT Quality Control - Supercharging

- Supercharging is the build up of high pressure around the borehole due to the hydrostatic head of the mud filtrate that has not dissipated after drilling.
- Usually associated with low permeability formations;
  - where the mud filtrate pressure has not had time to equilibrated to formation pressure,
  - and/or where the thin mud cake does not adequately isolate the formation from the borehole.
- Supercharging can be a bigger problem with LWD as there is active mud circulation.



Low permeability formation can have thin or no mud cake

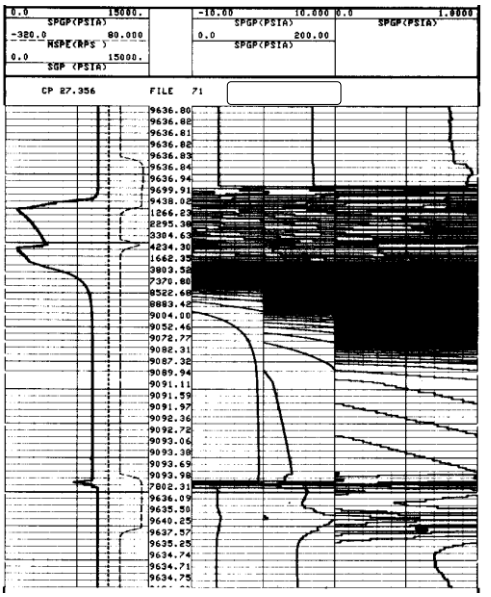
FPT Quality Control

Supercharging

- Really big draw-down, buildups back towards hydrostatic
- not stable
- low formation permeability
- Does not give valid formation pressure

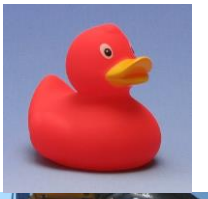
papers on trying to correct for supercharging;

- *Mark A. Proett and Wilson C. Chin, 1996; Supercharge Pressure Compensation Using a New Wireline Testing Method and Newly Developed Early Time Spherical Flow Model SPE-36524*
- *Russ A. Schrooten et al, 2007. A Case Study: Using Wireline Pressure Measurements To Improve Reservoir Characterization in Tight Formation Gas--Wamsutter Field, Wyoming. SPE-109565*



NB: this is an older field print with time increasing from top to bottom

Formation Pressure Testers - Back to Basics.



Summary;

- Formation Pressure Testers are GREAT tools.
- What happens when we drill a well ?
  - We change the formation and the fluids.
- Some thoughts on planning FPT acquisition.
  - Involve the service company and the well engineers
  - Plan for safe operations and don't compromise on safety
- How do FPTs work and where do the pressures come from ?
  - QC the depths.
- FPTs - how do we run the tool ?
- How do we know the formation pressures are okay ?
  - QC the pressures.
- What else should we worry about ?
  - Oil field units and those conversion factors.

Bonus Slide 1 - Formation Pressure Testers - *What's in a name ?*

- **FPT** - formation pressure tester, not a company trade name, and not specific to conveyancing.
- ***WFT*** *- wireline formation tester, not a company trade name, but specific to wireline.*

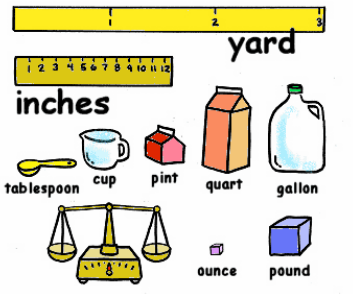
- ***Some of the many Company specific trade names (in alphabetically order);***
  - ***DFT*** *- drilling formation tester*
  - ***FMT*** *- formation multi-tester*
  - ***GeoTap***
  - ***MDT*** *- modular dynamic tester*
  - ***MFT*** *- compact formation pressure tester*
  - ***PressureWave***
  - ***RCI*** *- reservoir characterization instrument*
  - ***RDT*** *- repeat dynamic tester*
  - ***RFS*** *- repeat formation sampler*
  - ***RFT*** *- repeat formation tester*
  - ***SFT*** *- sequential formation tester*
  - ***SFTT*** *- sequential formation test tool*
  - ***SRFT*** *- slim-hole repeat formation tester*
  - ***StethoScope***
  - ***TesTrak***
  - ***XPT -*** *pressure-xpress*

Some examples of EWL and LWD FPT logging tools

Bonus slide 2 - What else is there to worry about ? Units

- **Oil field units include**;
  - depth - feet or metres
  - volumes - barrels, cubic feet, cubic centimetres, gallons, (US or Imperial ?)
  - fluid density - g/cc, lb/cubic-foot, ppg, SG
  - pressure - psi or Bar; - gauge or absolute ?
  - pressure gradients - psi/ft or psi/m or bar/m
  - ✓ time - seconds
  - permeability – milli-Darcies
  - viscosity - centipoise
  - temperature – degrees Fahrenheit or Celsius
- Often need conversion factors which increases the chance of error

- **SI units**
  - depth/length/diameter - metres, millimetres
  - volumes - cubic metres
  - pressure - Pascal
  - fluid density - kg/cubic-metre
  - permeability – square metres, square millimetres
  - ✓ time – seconds (but not minutes and hours)
  - temperature - Kelvin
  - viscosity - pascal-second



Bonus Slide 3 - Formation Pressure Data - Some notes on fluid levels

Some capillary pressure theory;

- due to buoyancy and gravity, hydrocarbons displace water from the reservoir, with the bigger pores (capillaries) displaced first and smaller pores later.
- Free water level (FWL), is where capillary pressure is zero.
- Oil or Gas water contact (OWC/GWC) is the first occurrence of hydrocarbons.
- FWL is not the same as GWC or OWC.
- *FWL - OWC = Entry Pressure Height*
- *Transition zone, between OWC and Irreducible Sw*

- <u>The intercept between water gradient and oil or gas gradient on gives FWL (not OWC or GWC)</u>