WATER ACTIVITY AND SHALE STABILITY

Presented by:
Dr. Martin Chenevert

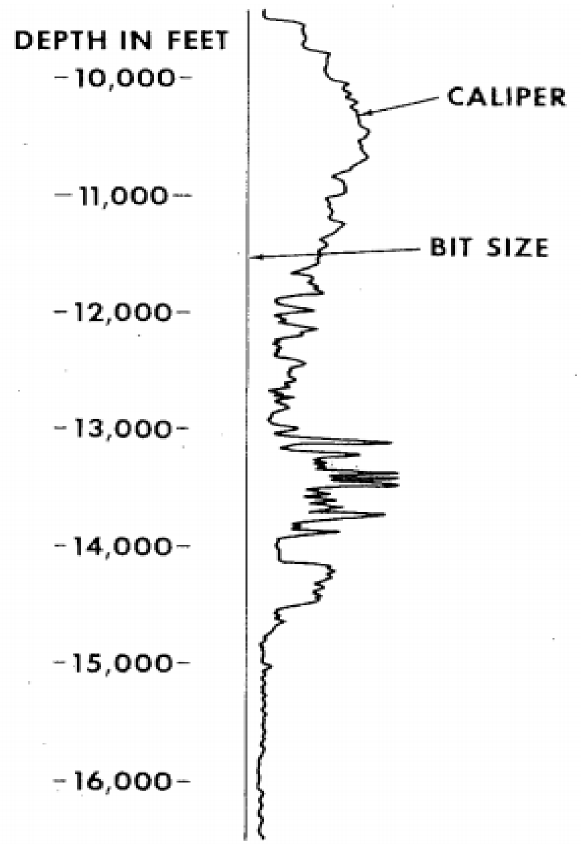
Water Activity and Shale Stability

- Objectives:
  - Know why shale react with water base muds
  - Understand the development of shale "swelling pressures"
  - Know how the various inhibitive muds work
  - Know the "total potential" for muds and shales
  - Know why salt water muds are not as useful as oil base muds
  - Know why balanced activity oil muds work
  - Understand water activity and measurement methods

AQUA LAB BY DECAGON

West Texas Hard Shale Cavings

Caliper Log, West Texas Hard Shale Water-Base Mud



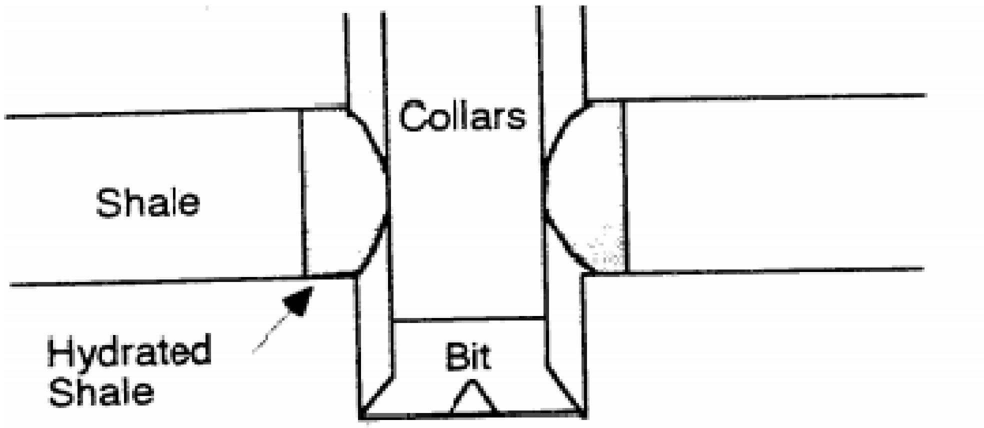
Wellsite Symptoms – Two Phases

- As shales are penetrated, they
  - first swell into the wellbore
  - break off and produce hole enlargement, fill on bottom, and add unwanted drilled solids to the mud

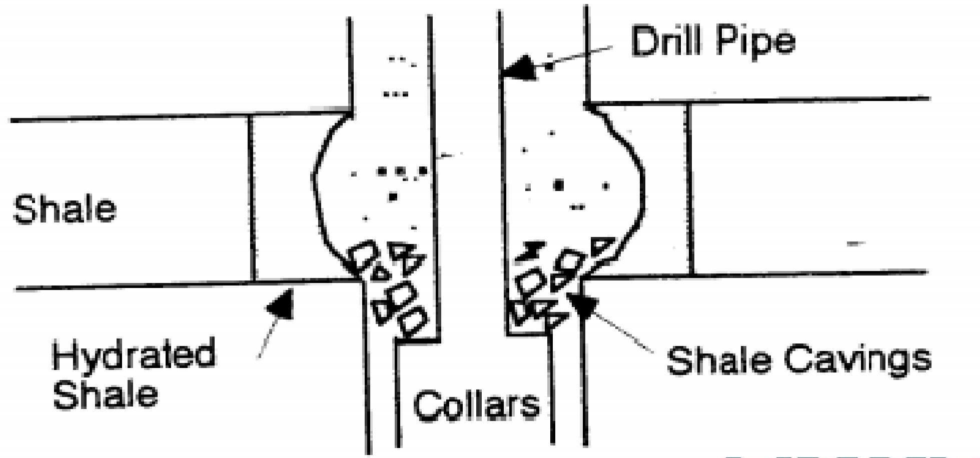
AQUA LAB BY DECAGON

Wellsite Symptoms – Two Phases

Phase 1:
Shale swells into wellbore,
a tight borehole is experienced



Phase 2:
Shale failure occurs, resulting in “cavings” on bottom, hole enlargement, and solids dispersing into the mud



Shale Properties

- Why do shales cause so many problems
  - Shales contain clays
  - The most troublesome clay is “Smectite” (Bentonite). One gram of Bentonite has a surface area of about 800 square meters, vs. typical sandstone with a surface area of only 10 square meters

Shale Swelling Mechanism

- The total potential of the wellbore fluid is the sum of hydraulic pressure, temperature, and if oil mud is used, the ionic content of the water phase
- The total potential of the water in the shale is the sum of hydraulic pressure, temperature, and the “adsorptive” tendency of the clay particles in their currently compacted state

Balancing Total Potentials

- The total potentials consist of hydraulic and osmotic pressures
- The total potential of the mud is equal to the pressure exerted by the mud weight, plus any salt ions which produce an osmotic effect in the wellbore
- The total potential of the shale is equal to the pore pressure plus the effect of salt ions and clays which produce an osmotic effect

- Let’s consider a simple osmotic cell analogy

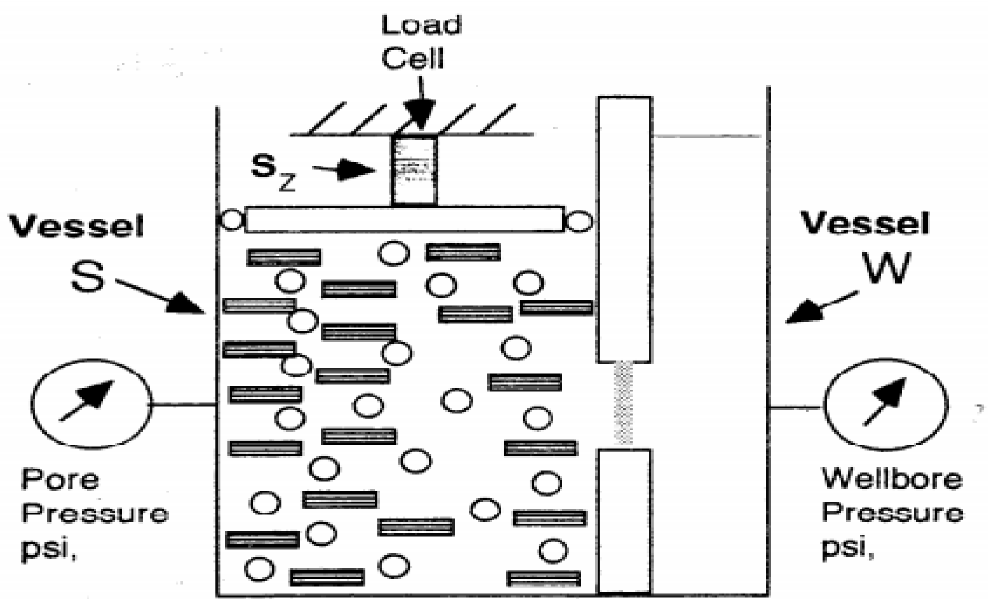
AQUA LAB BY DECAGON

Osmotic Cell Analogy

- Osmotic swelling pressure develop on the surface of a vessel when fluid moves into a vessel which has fixed boundaries
- Osmotic pressures developed in a shale

Osmotic Cell Analogy

- The vessel on the left represents a shale contains salt ions and clays. These elements reduce the chemical potential of the water. The vessel (wellbore) on the right contains fresh water which contains no salt ions, thus it has a high chemical potential
- When a bit penetrates such a shale, a difference in chemical potential drives the water into the shale and swelling pressures develop



Magnitude of Swelling Pressures

- Swelling pressures which are generated by an imbalance in water activities can be calculated using the equation:

$$P_{\pi} = \frac{RT}{\bar{v}} \ln\left(\frac{a_{ws}}{a_{wm}}\right) \text{, atm}$$

- R is the universal gas constant, T is the temperature in degrees Kelvin, and $\bar{v}$

  is the partial molar volume of pure water (0.018)

Magnitude of Swelling Pressures

- Example: for a mud and a shale at 100C (373 K), if the water activity of the shale is 0.85, and the water activity of the oil mud is 1.00, then the swelling pressure which can develop is:

$$P_\pi = \frac{(0.08205)(373)}{0.018} \ln\left(\frac{0.85}{1.00}\right) = -276atm$$

$$P_\pi = (-276atm)(14.7psi/atm) = -4062psi$$

Magnitude of Swelling Pressures

- Which way will the water flow and why?
  - Water will flow from the higher chemical potential (a_{wm}= 1.0) to the lower chemical potential (a_{ws} =0.85)
- When does the water stop moving?
  - Water will keep flowing into a shale until total potentials are equal

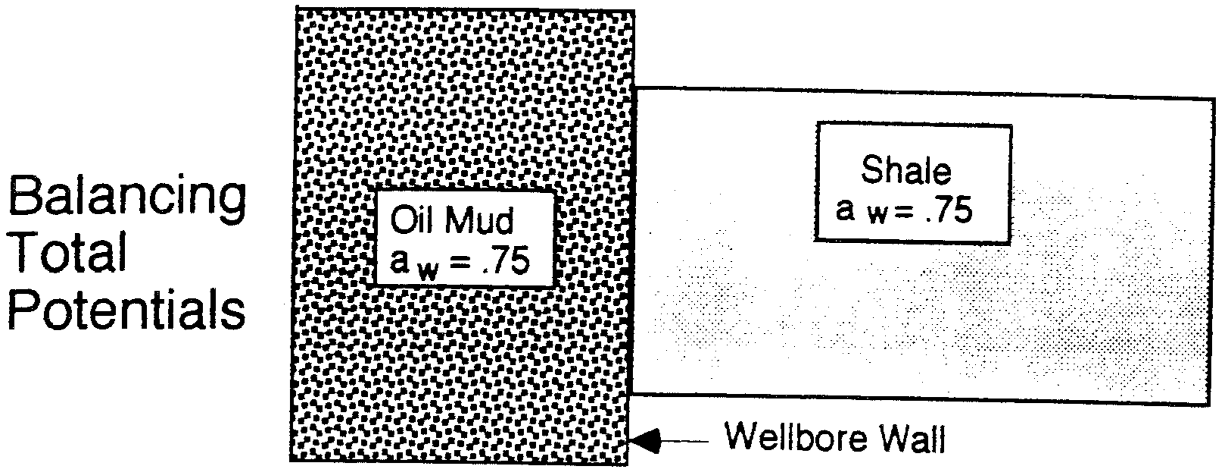
AQUALAB BY DECAGON

Osmotic Properties of Oil Muds

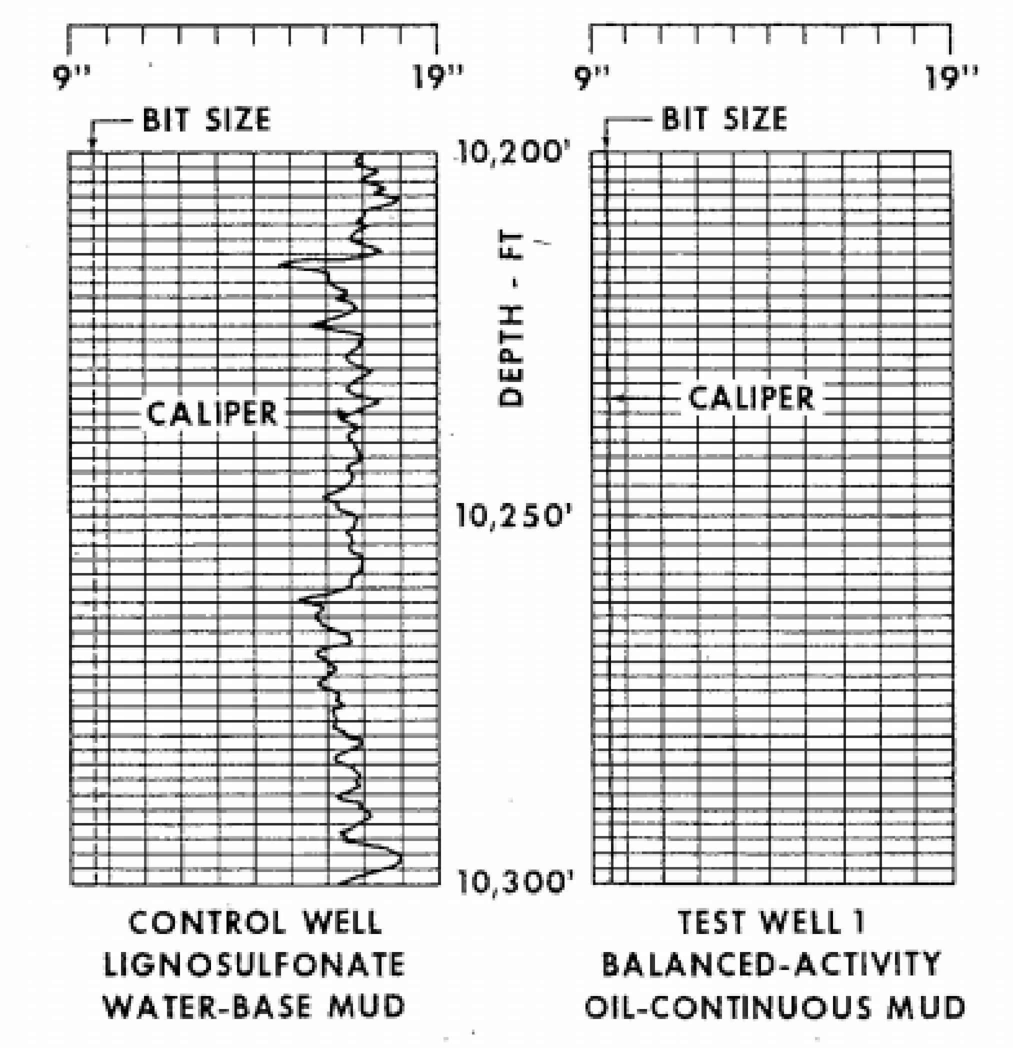
- The total escaping tendency of the emulsified water in an oil base mud is greatly reduced by adding a high concentration of salts (such as CaCl2 or NaCl). In addition, a semi-permeable membrane surrounds each salt water droplet which restrict the flow of ions into the shale. The salt ions prevent the water movement and the membrane prevents the ion movement. This develops an effective osmotic pressure mechanisms which offsets the osmotic suction of the shale

Osmotic Properties of Oil Muds

- One property of a mud which reflects the total escaping tendency of the water is "water activity (a_w)". This is defined as, $a_w = p_w/p_w^o$, where p_w is equal to the vapor pressure of the water in the mud and p_w^o is the vapor pressure of pure water at the same temperature



Caliper logs, West Texas Hard Shale



Water Activity Definition

- Water activity is derived from fundamental principles of thermodynamics and physical chemistry.
  - Standard State (Pure Water) is defined
  - System must be in equilibrium
  - Temperature must be defined

Water Activity Definition

- Water Activity is a measure of the energy status of the water in a system.

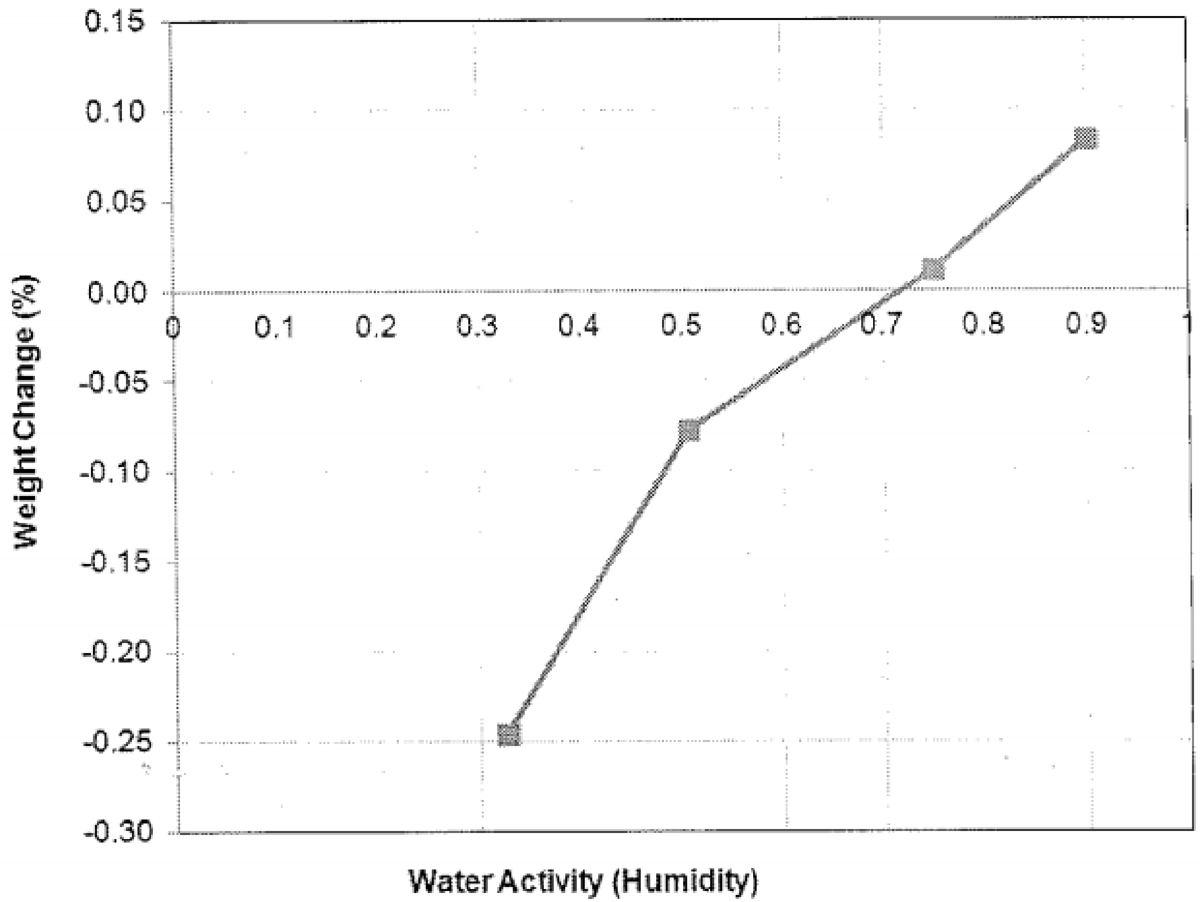
$$a_w = f/f_o = p/p_o$$

$$a_w = \frac{\text{Vapor pressure of water above sample @ °C}}{\text{Vapor pressure of pure water @ same °C}}$$

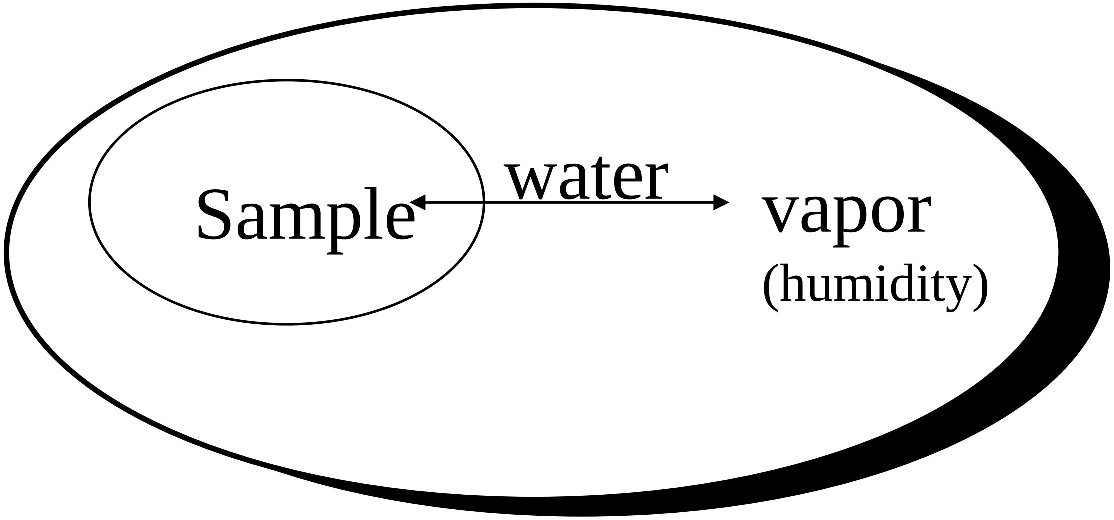
$$a_w = \text{ERH (\%)} / 100$$

AQUALAB BY DECAGON

Native Water Activity of Eagle Ford Shale



Water Activity Instrumentation



Water Activity is measured by equilibrating a product with the vapor phase and measuring the relative humidity of the vapor phase.

AQUA LAB BY DECAGON

Water Activity Instrumentation

- Water activity measurement methods
  - Hair or polymer hygrometers
  - Electrical hygrometers
  - Chilled mirror dew point

Electrical Properties Sensors

- Advantages:
  - Accuracy: +/- 0.02
  - Relative insensitive to volatiles
  - Measures entire range

- Disadvantages:
  - Needs calibration (secondary method)
  - Need temperature control or compensation of sensor
  - Some sensor hysteresis

AQUA LAB BY DECAGON

Chilled Mirror Dew Point

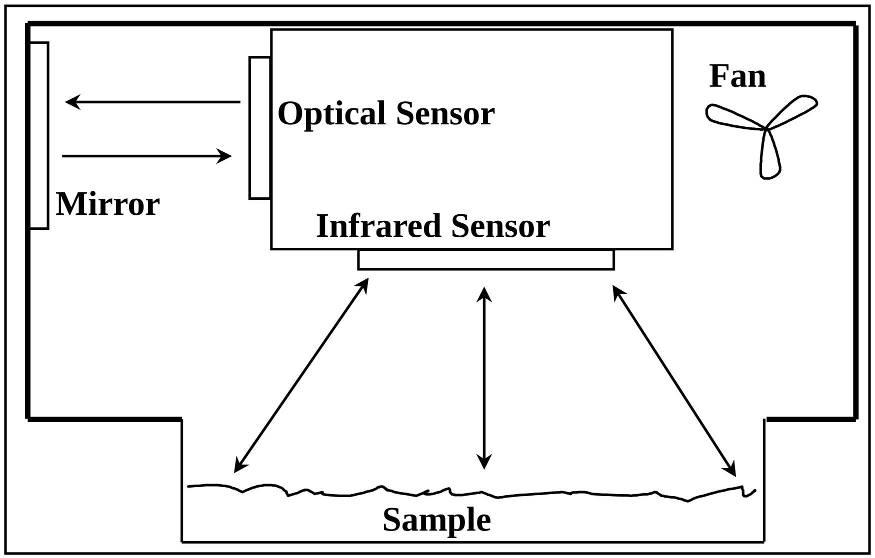
- Advantages:
  - Primary method of measuring vapor pressure
  - Highest accuracy ±0.003a_w
  - Rapid measurement <5 minutes
  - Measures entire a_w range (0.03 – 1.0a_w)
  - High reliability

- Disadvantages:
  - Need clean mirror
  - Readings affected by alcohol and propylene glycol

AQUA LAB BY DECAGON

Chilled Mirror Dew Point

- AquaLab 4TE Dew Point Water Activity Instrument



Questions ?

- Dr. Martin Chenevert

- AquaLab by Decagon
- applications@aqualab.com
- 509-332-2756