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Practical Approach to Solving Wellbore Instability Problems

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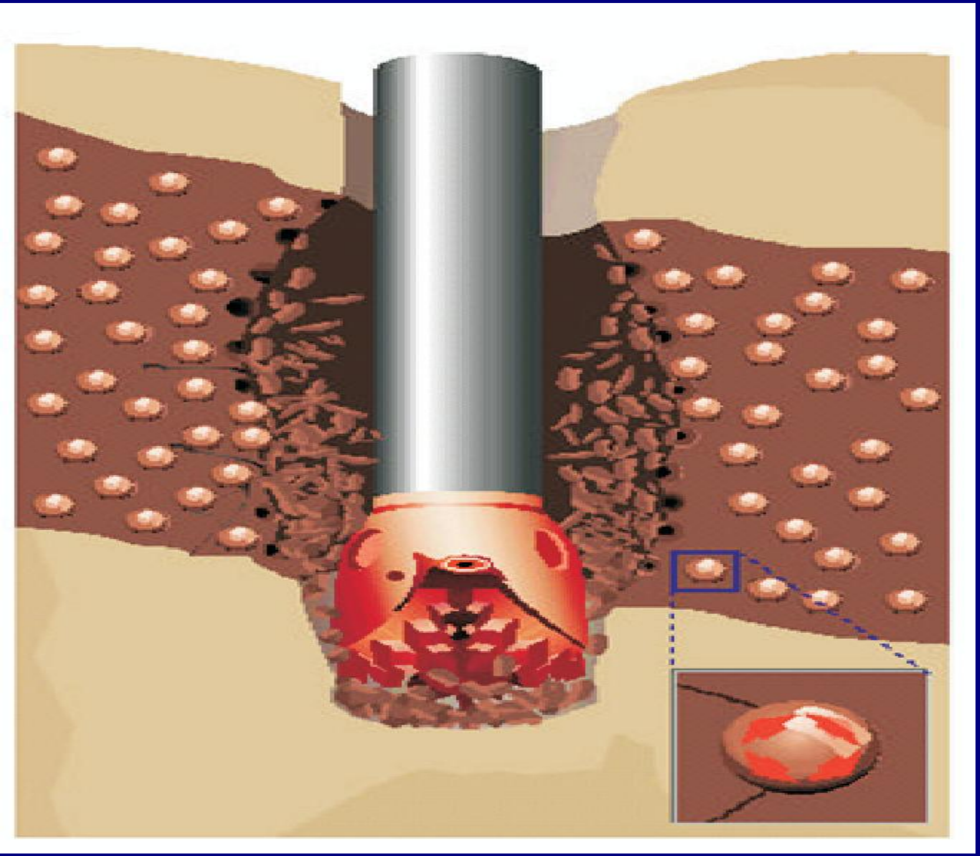
Outline

- Introduction & Objectives
- Causes of Wellbore Instability
- Wellbore Stability (WS)
  - Before Drilling; While Drilling; & After Drilling
- Symptoms, Prevention & Remedial Actions
- Case Studies
- Summary & Conclusions

Introduction

Introduction



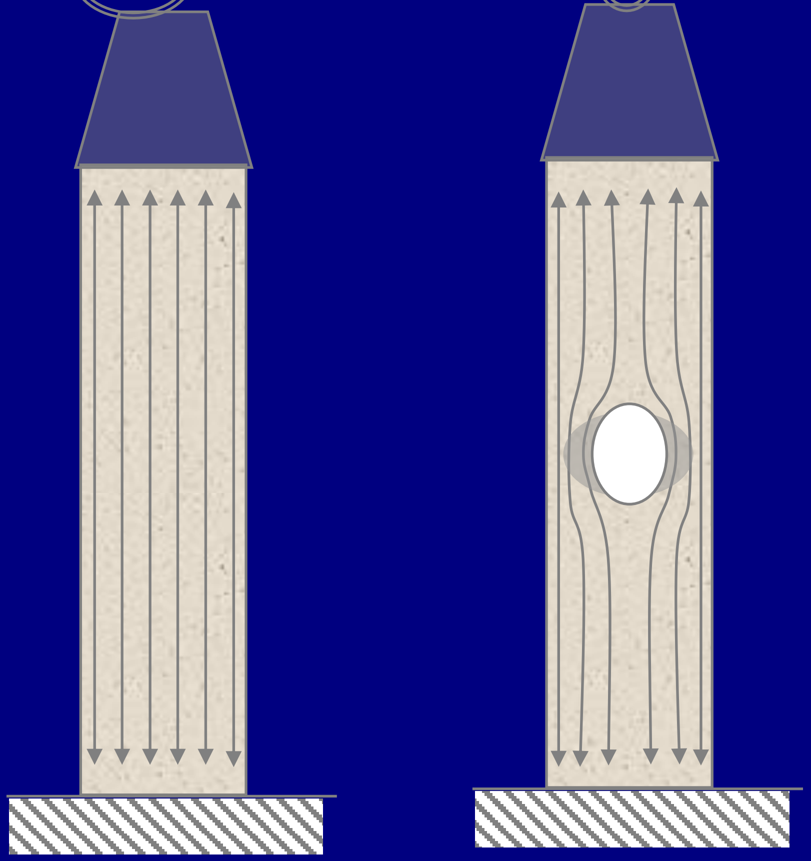
- Wellbore instability (WI) is recognized when the hole diameter is markedly different from the bit size and the hole does not maintain its structural integrity.

  Overgauged or undergauged hole $\Rightarrow$ WI

Why Wellbore Instability?

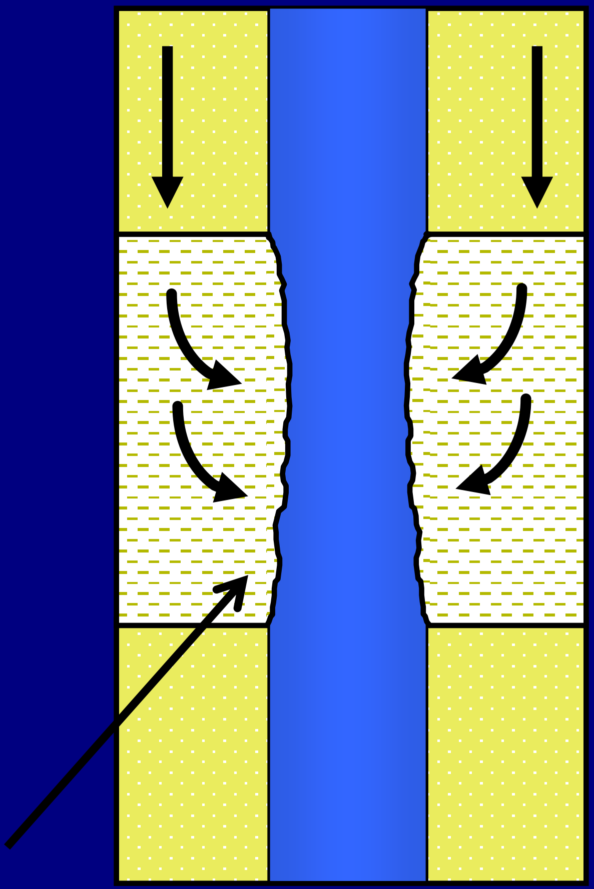
- We caused it. How? The creation of a circular hole into an otherwise stable formation.
- Hole tends to collapse or fracture unless supported
- Some rocks are very strong and will support themselves better than weaker rocks.

SIMILAR TO CORROSION



Introduction (cont’d)

- Some phenomena that cause wellbore instability are:
  - Removal of the confinement condition
  - Creation of stress concentration field around the wellbore
  - Inelastic and time-dependent displacement of the wellbore caused by the creation of free surface
- Bottom line: Forces acting in the formation push the wall of the hole inward. If not stabilized with mud weight, the hole will collapse



Consequences of Wellbore Instability

- These are:
  - At least reduced drilling performance and/or stuck BHA & downhole tools $\Rightarrow$ fishing
  - Loss of equipment and sidetracking
  - Excessive trip time and reaming time
  - Poor hole logging; inability to land casing; and poor cementing conditions/jobs
  - At worst it can lead to total collapse and loss of the hole
- Bottom Line: increase in non-productive time and increase in total drilling cost.

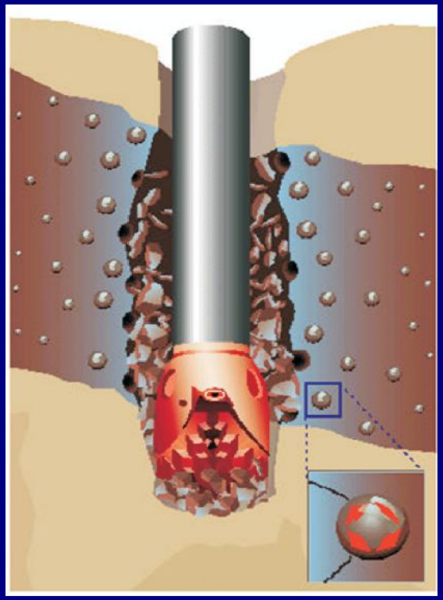
Objectives

1. To describe causes of wellbore instability problems
2. To describe wellbore stability before, during, and after drilling wells
3. To describe symptoms of the problems while drilling
4. To discuss practical, preventive, and remedial actions for wellbore instability

Causes of Wellbore Instability

Causes of Wellbore Instability

Grouped under three interrelated headings



1. Mechanical

2. Rock-Chemical Interaction (Shale)

3. Man-Made (Drilling Practices)

Causes–due to uncontrollable or controllable factors. Understanding these causes is important in maintaining & controlling wellbore stability

1. Mechanical Wellbore Instability

- Key parameters are:

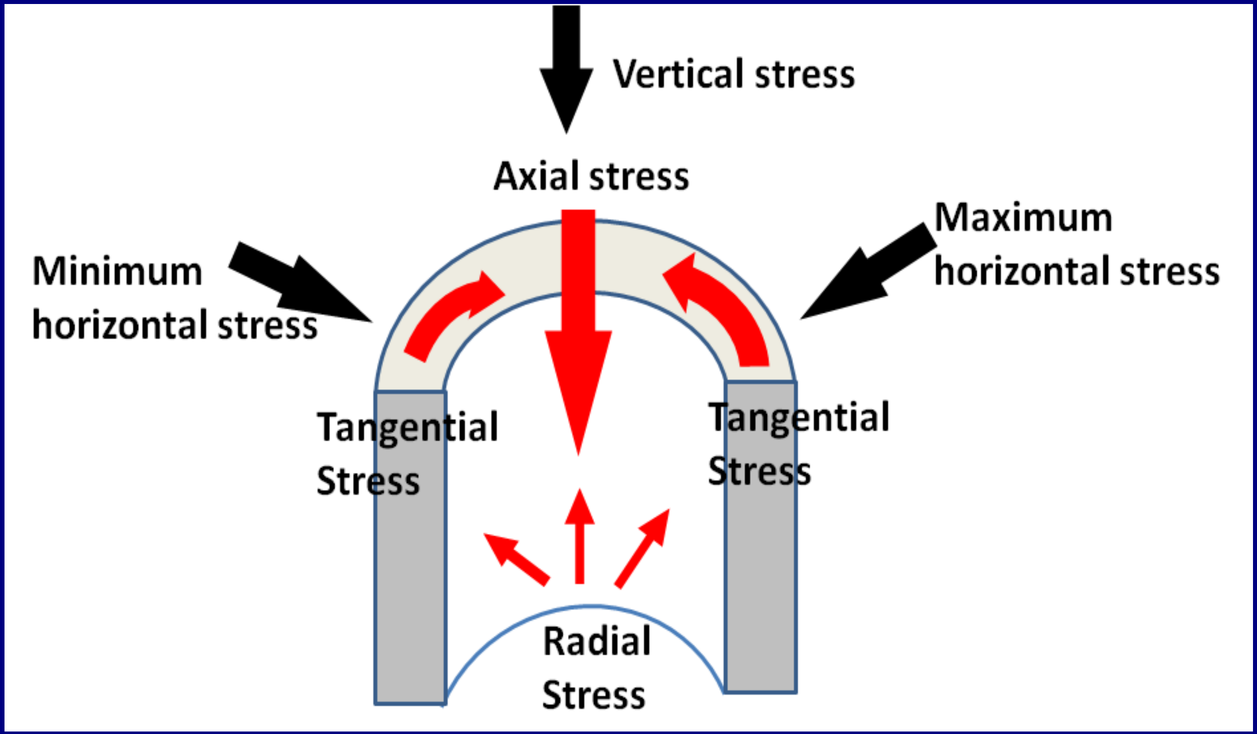
1. Rock Stresses/Rock Types
2. Rock Strength (weaken)
3. Wellbore Geometry (Hole Inclination & Azimuth)
4. Man-Made Related Stresses

- First two are uncontrollable and the last two are controllable

Mechanical Wellbore Instability

- Mechanical failure occurs when wellbore stress concentrations exceed the rock strength
- Wellbore stress concentrations result from
  - Drilling into pre-stressed rock (earth stresses)
  - Excessive wellbore pressures
  - Drillstring vibrations

Wellbore Stresses After Drilling



- Before drilling, the rock is in a state of equilibrium

- Drilled wellbore results in a ‘new’ set of stresses known as **wellbore stresses – axial, tangential, and radial (mud hydraulic pressure)**
- If the redistributed stress-state exceeds rock strength, instability may result.

Mechanical Wellbore Instability - Borehole Stress Orientation

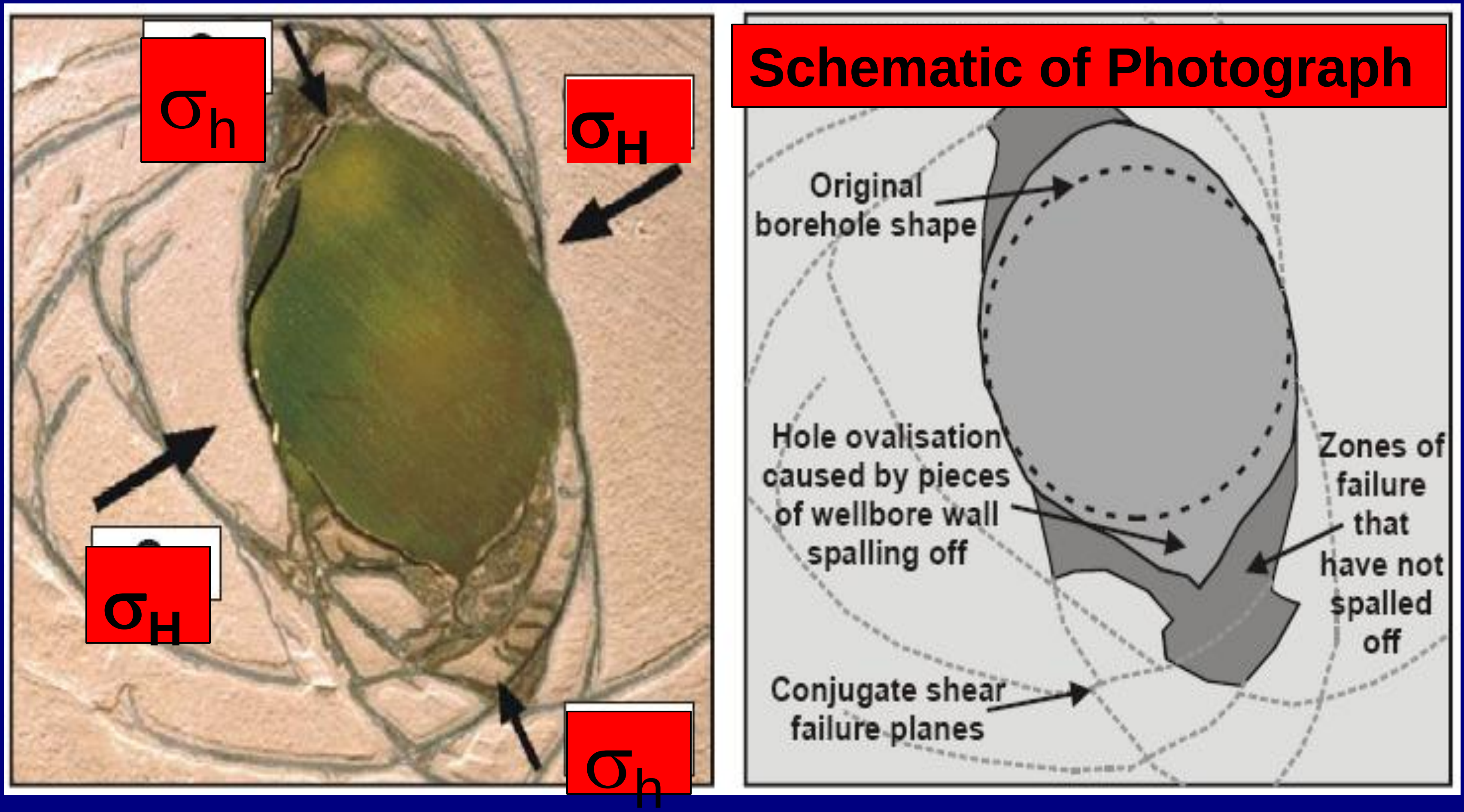


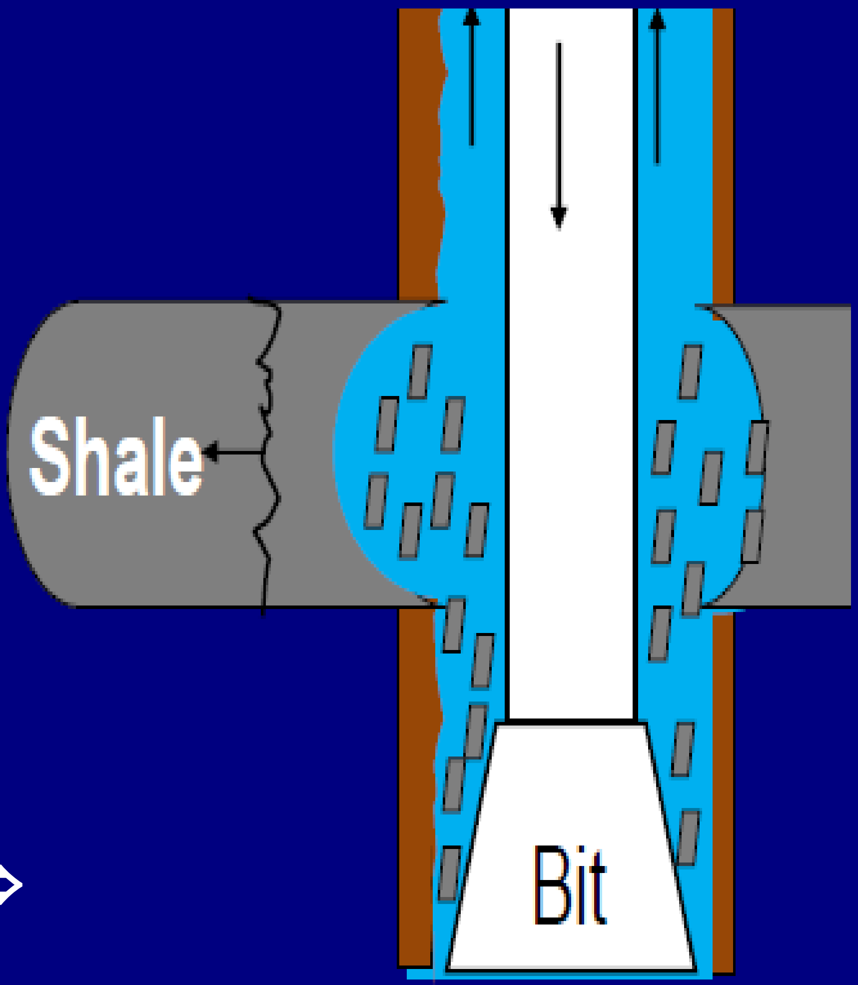
Figure shows results of a hollow cylinder lab test simulating borehole breakout (2 unequal horizontal stresses) - CSIRO Division of Geomechanics (J. Reinecker et al., 2003)

2. Rock-Chemical Interaction (Shale) Instability

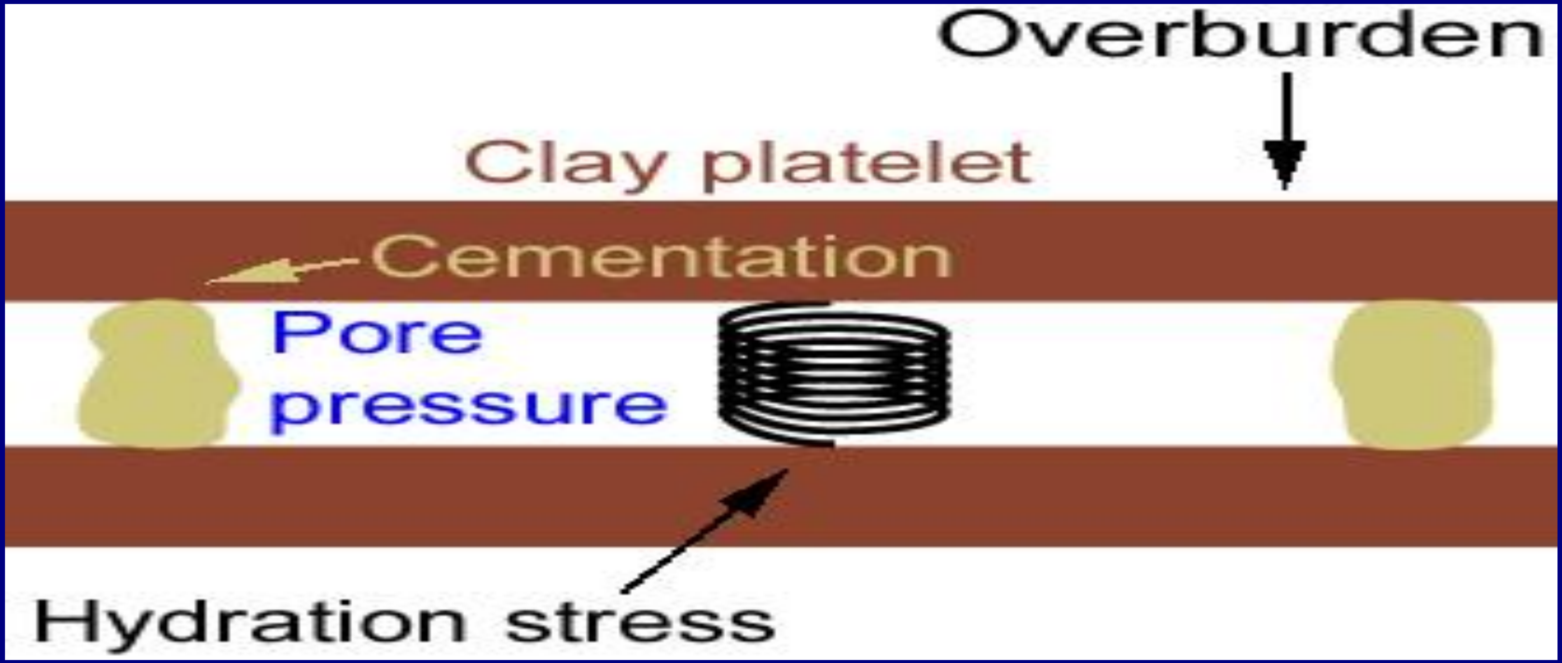
- Sedimentary rocks in general are shales (75%) and in particular they are sensitive to their chemical environment.
- Reaction between the shale and drilling fluid causes the shale to swell, weaken, and eventually fall/collapse into the wellbore.
- Solution is to have a drilling fluid system that balances the mechanical and chemical forces.
- Also use drilling practices that minimize shale or formation instability.

Shale Instability

- Causes are twofold:
  1. Time-dependent swelling of shale formation
  2. Shale swells, weaken, and eventually fall/collapse into the wellbore.
- The figure shows shale adsorbing fluid filtrate ⇒ shale swelling & other problems.

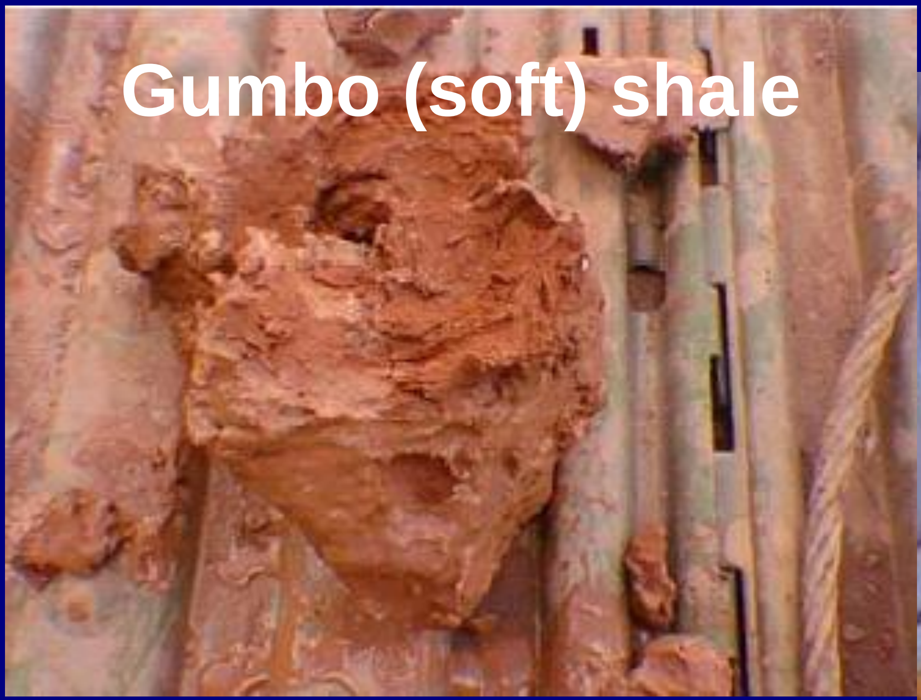


Shale Hydration Mechanism



- Forces holding plates together: Overburden & Cementation
- Forces pushing plates apart: Pore Pressure & Hydration Stress (can be up to 80,000 psi = 5700 atm.)
- Shale types: smectite (worst), illite, kaolinite, chlorite, & mixed layers

Symptoms of Shale Hydration

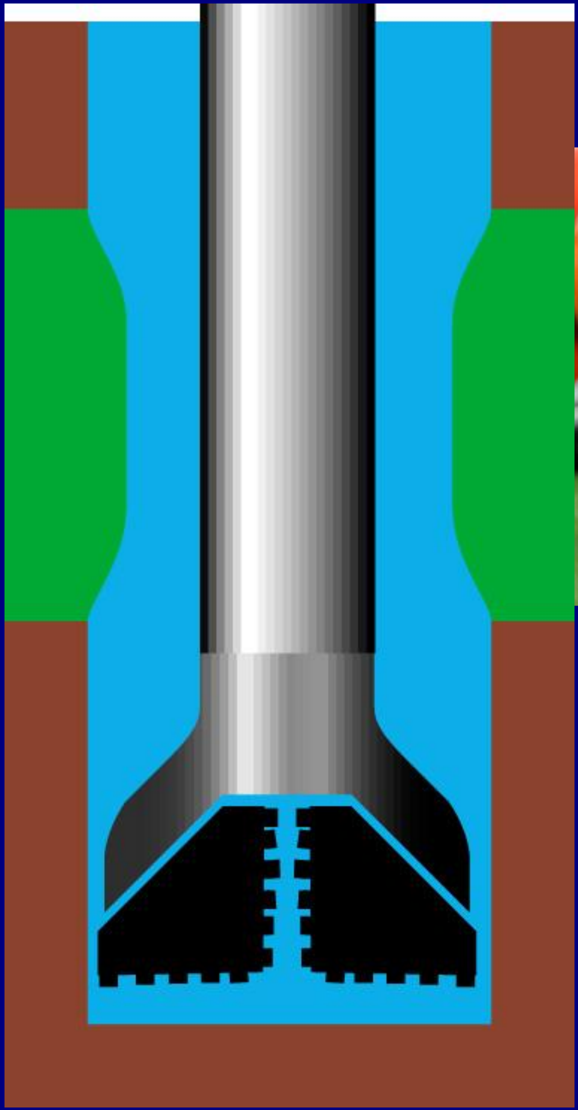


Others: clay balls on the flow line; tight hole when tripping & problems logging

Symptoms of Wellbore Instability

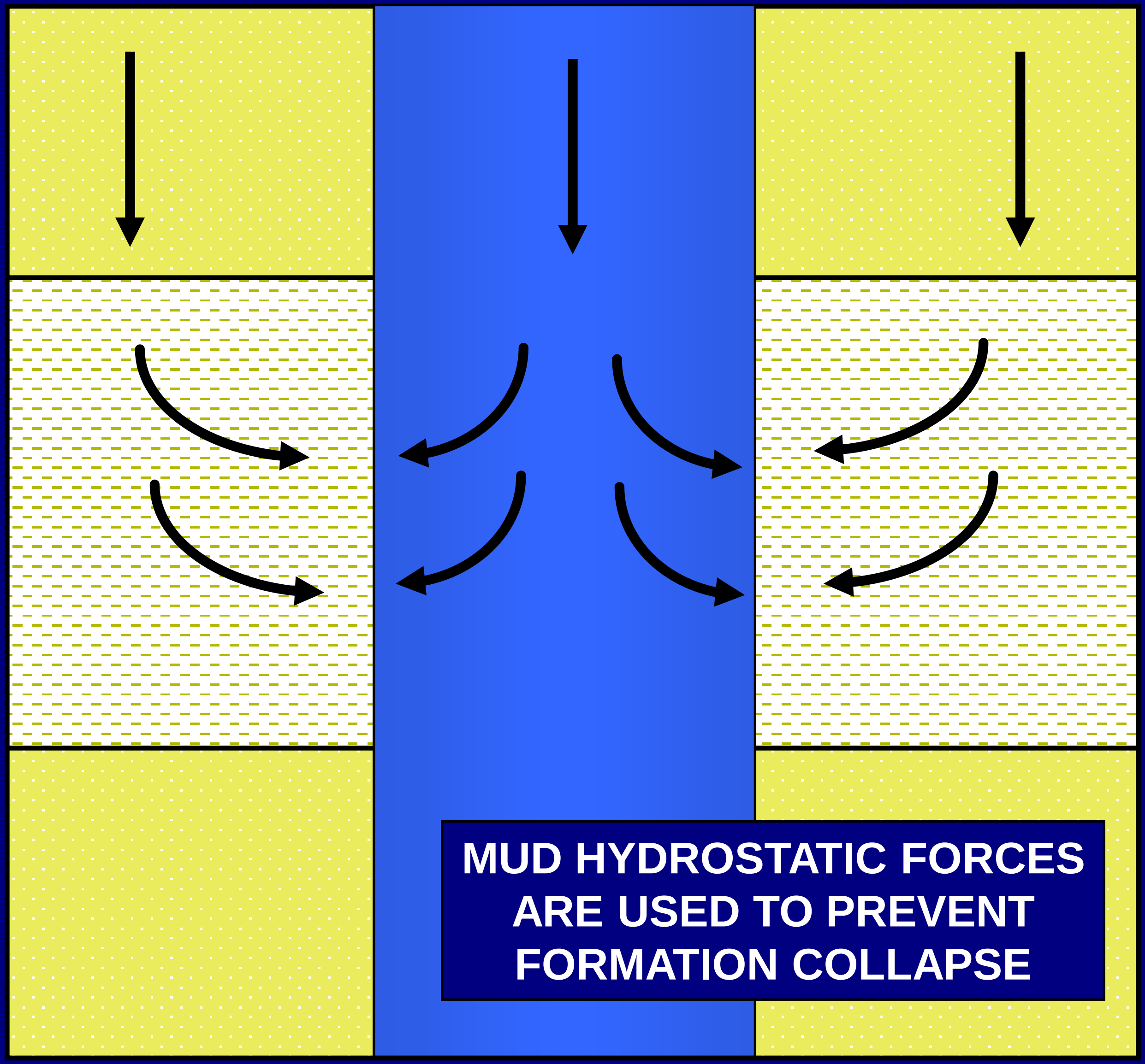
- Tight hole, drag while tripping, logging problems & stuck pipe
- Solutions: Raise mud weight, alter mud chemistry or change mud type, run casing ASAP

Plastic Deformation and Creep



Common with shale and salt formations due to reaction with water/stress change

Mud Hydrostatic Pressure



3. Man-Made Wellbore Instability

- Lack of adequate well planning
  - Selection of wrong inclination & azimuth
  - Selection of wrong drilling fluid system
- Improper (poor) drilling practices
  - Excessive wellbore stresses
  - Poor hole cleaning
  - Excessive drillstring vibrations

Wellbore Stability (WS) Before Drilling (Planning)

Wellbore Stability (WS) Before Drilling (Planning)

- Involves: geo-mechanics and drilling fluid selection
  - A comprehensive GeoMechanics study is essential in order to understand causes of wellbore instability and to improve drilling design and drilling performance.
    - Extremely important for horizontal & extended reach wells.
  - An extensive shale inhibition testing program is also essential.

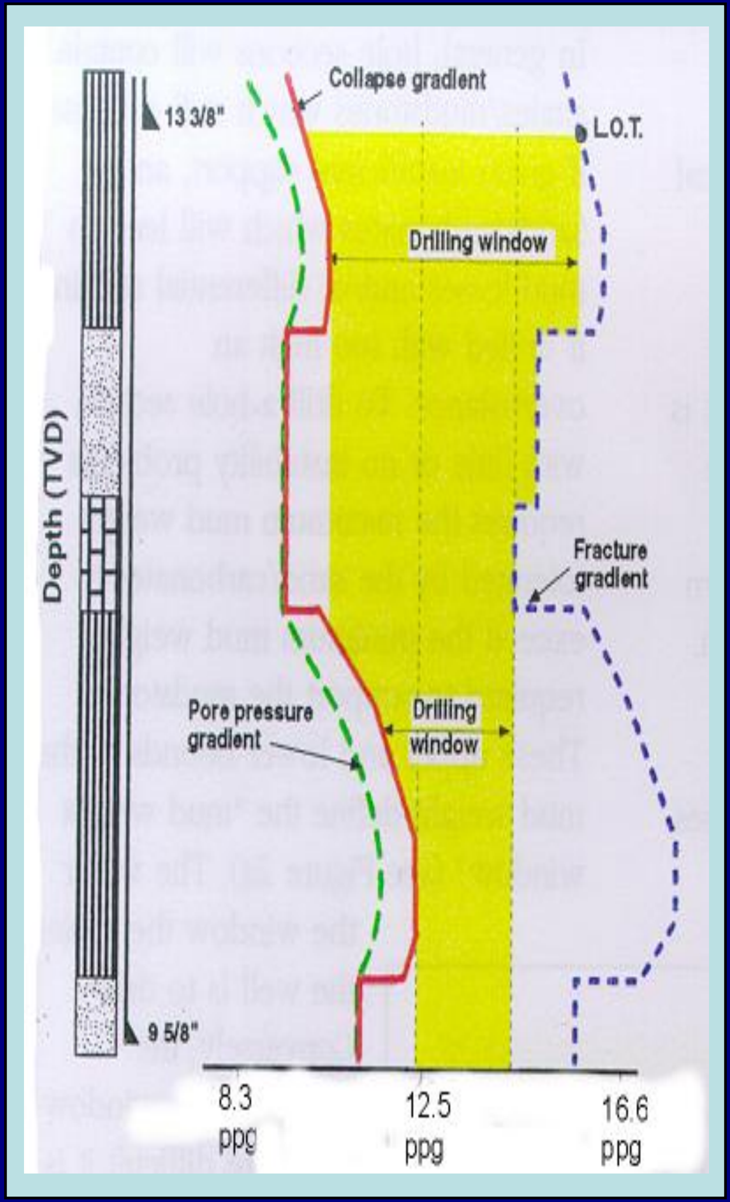
Wellbore Stability (WS) Before Drilling (Planning)

- Steps for GeoMechanics study are:
  - To acquire, audit & perform quality control of geomechanical data (e.g. wireline logs)
  - To build Mechanical Earth Model (MEM)
  - To perform WS analysis of the planned well including trajectory sensitivity analysis
  - To review wellbore instability drilling events from offset wells
  - To forecast wellbore stability

Wellbore Stability Before Drilling (Planning)

- **Geo-Mechanical Earth Model**
  - Integrate all geo-mechanical data available from a field/basin into one “database”
  - Use model to predict wellbore instability problems in an upcoming well
  - Model outputs – (1) safe mud weight window and (2) safest inclination & azimuth to drill.

Mud Weight Window



- While drilling some rock types try to collapse & some are easily fractured. This can cause problems in deciding on correct mud weight (MW). Too high a MW may fracture a sand or limestone but too low a MW may cause some shales or salts to squeeze into the hole.

- The difference between a min. and max. weight is called the '**mud weight window**'. The wider the window, the easier it is to drill the well.

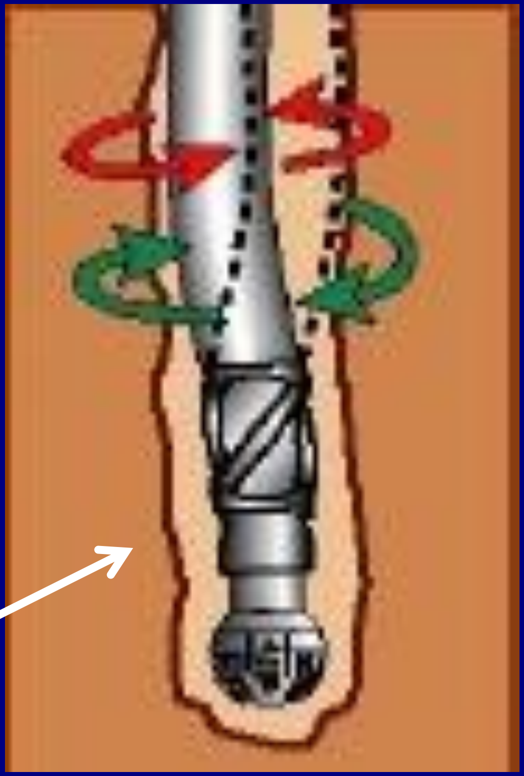
Shale Inhibition Test Methods

- Wellbore Simulators - swelling stress/strain tests under HTHP (lab) – to model fluid flow in shale (shale permeability)
- Cuttings Dispersion - evaluation of mud type (lab & rig site)
- Cation Exchange Capacity (aka MBT) – use to determine shale type

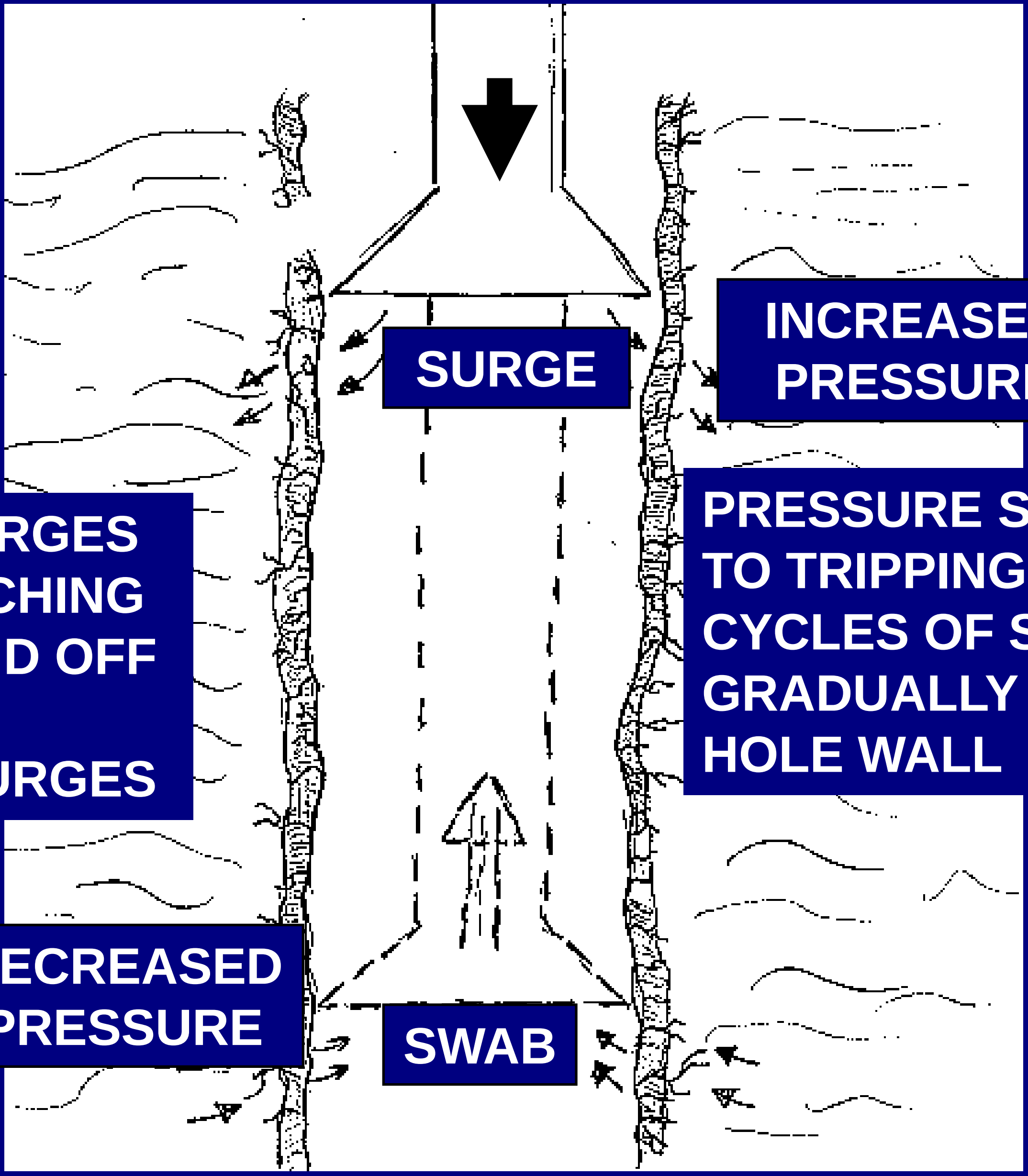
Wellbore Instability While Drilling – Improper Drilling Practices

Excessive Wellbore Stresses

- Causes
  - Surge/swab pressures cause the wall to weaken
  - Poor hole cleaning ⇒ cutting accumulation ⇒ high equivalent circulating density (ECD)
  - Excessive drill string vibrations



Excessive Wellbore Stresses

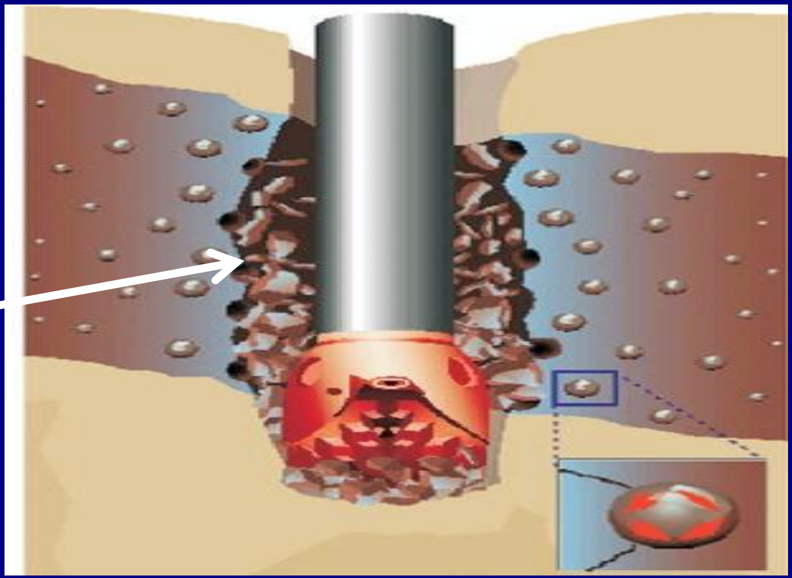


ALSO ECD SURGES WHEN SWITHCHING PUMPS ON AND OFF WILL CREATE PRESSURE SURGES

PRESSURE SURGES DUE TO TRIPPING CAN CREATE CYCLES OF STRESS THAT GRADUALLY WEAKEN THE HOLE WALL

Symptoms of Excessive Stresses

- Large amounts of blocky cavings on shale shaker; more after wiper trip; borehole failure due to stress changes in massive shales
- Hole enlargement
- Erratic directional control



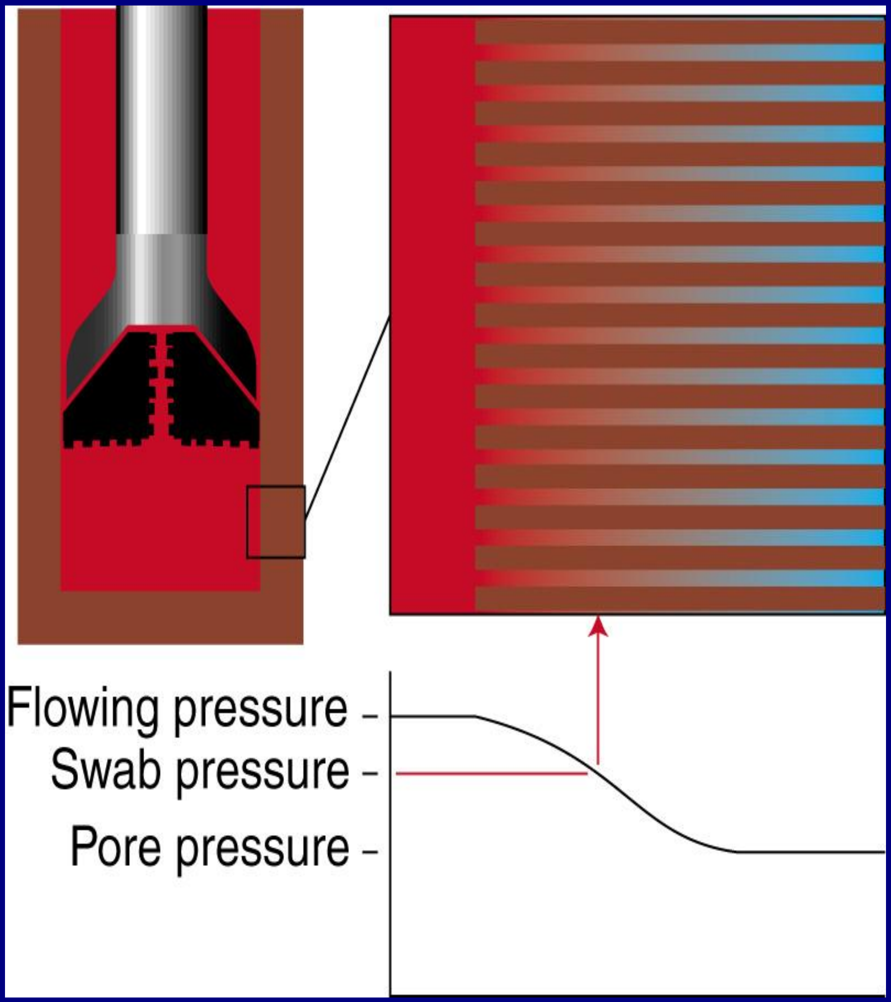
Symptoms of Wellbore Instability

- Lots of cuttings on the surface.
- Borehole failure due to stress changes in massive shales

- **<u>Solution</u>**: One solution is to raise mud weight

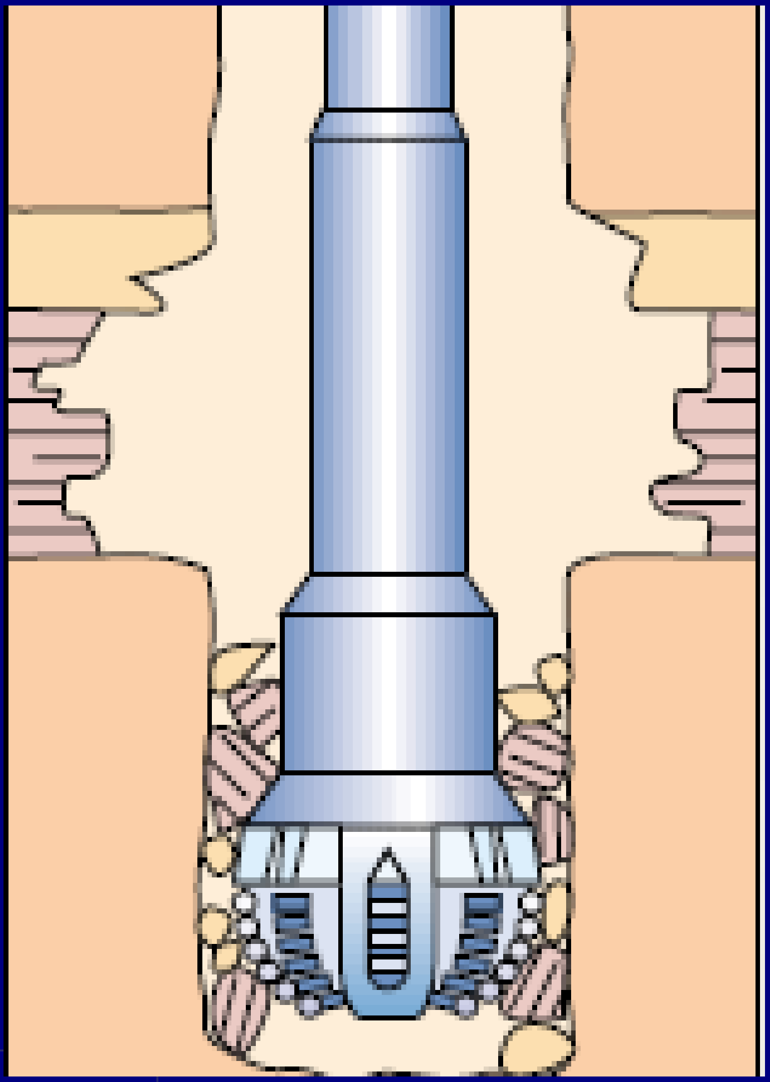
Pore Pressure Penetration

- Causes:
  - Poor hole cleaning
  - Localized elevated pore pressure
- Symptoms
  - Tensile cavings
  - More cavings after trips



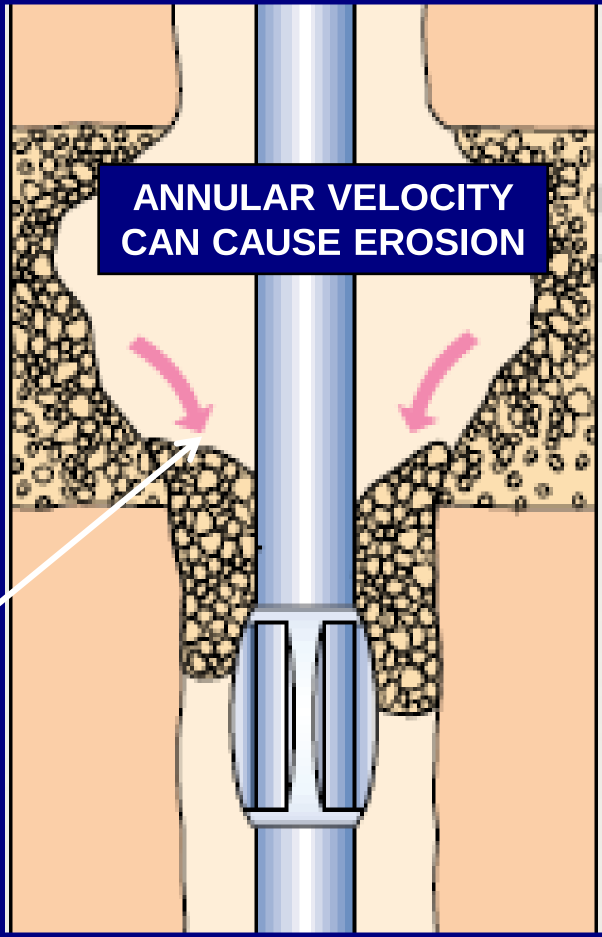
Instability in Fractured Rocks

- <u>Causes:</u>
  - Time-dependent mud penetration into fractures
  - Stress changes ⇒ weaken formation
- <u>Symptoms</u>
  - High levels of angular cavings
  - More cavings after wiper trips



Instability Due to Erosion

- **Causes:** Erosion occurs mostly at the bit & hole wall due to:
  - Excessive circulation rate
  - Common in weaken and unconsolidated formations
- **Symptoms**:
  - Over-gauged hole
  - Erratic directional control



Wellbore Stability While Drilling

- Involves real time WS management (control): This is a 2-fold process:

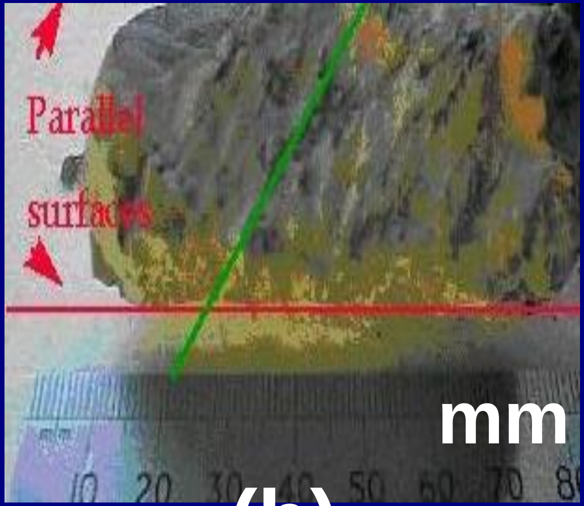
1. Continuous monitoring – caving analysis, downhole measurements (MWD and LWD) and surface signatures to diagnose onset of a problem
2. Remedial actions – involve control of surface parameters such as WOB, mud weight, flow rate, etc.

Wellbore Stability While Drilling

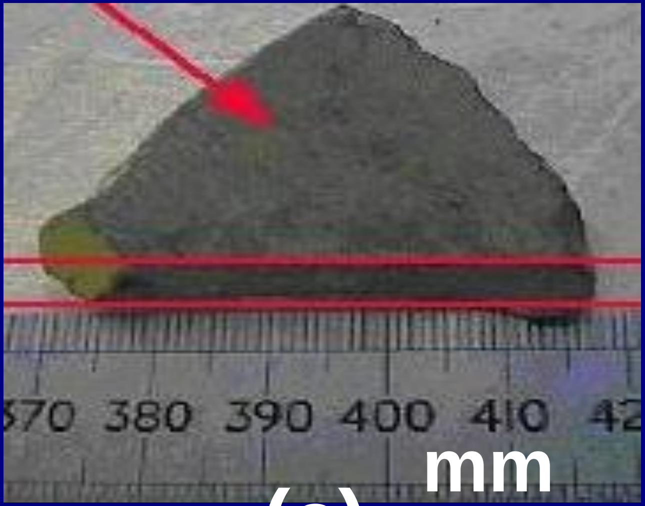
- Caving Analysis: A key parameter to managing wellbore instability in real time; provides an early warning of wellbore instability
  - Monitor caving rate
  - Perform caving morphology
    1. Types of cavings: Tabular, Angular, or Splintered

Caving Analysis - Tabular Cavings

(a)



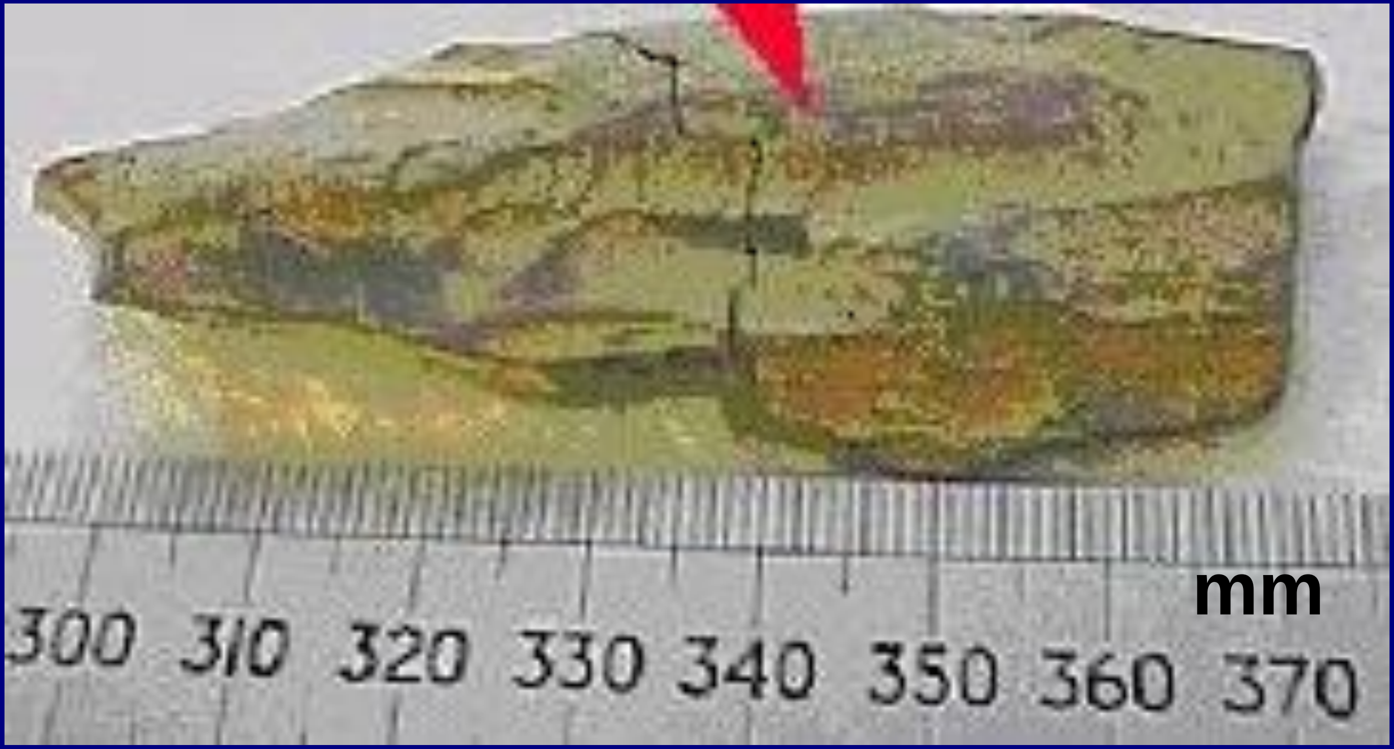
(b)



(c)

- (a), (b) Natural fractured cavings - have flat & parallel faces; & beddings are not parallel to the faces
- (c) Weak plane cavings - have flat & parallel faces; bedding direction also parallel to the faces.

Angular Cavings



- Angular – from borehole breakouts (have curved faces with rough surface structure)

Splintered Caving

- From over-pressured zones (concave flat, thin, & planar in structures)

Downhole & Surface Measurements

- Run tools to monitor annular pressures (APWD), hole diameter (caliper log), & downhole vibrations to diagnose onset of a problem
- Control surface parameters (WOB, RPM, flow rate, mud weight, & rheology) to fix a failed or failing wellbore.

Remedial Actions While Drilling

Remedial Actions for Wellbore Instability

- Depend on type of instability and its severity
- Involve integration of the three causes: mechanical, rock-chemical interaction, & man-made instabilities
  - May be problematic in some cases. Why? Rocks are not identical

Remedial Actions for Wellbore Instability

- ROP and hole cleaning efficiency.
  - Continuously monitor cavings (analysis)
  - Monitor hole cleaning & reduce ROP if necessary
  - Control surface parameters
- Improve drilling practices: trip wisely (1 stand/minute) & minimize wiper trips
- If everything fail, case the well ASAP

Wellbore Stability After Drilling

Wellbore Stability After Drilling

- This is Post-Drilling Review. Involves
  - Acquiring relevant geomechanical data, analyzing same and updating Mechanical Earth Model (MEM)
  - Reviewing all drilling events leading to wellbore instability
  - Reviewing planned WS action with actual performance, and analyze differences

New Developments for Solving Wellbore Instability Problems

- Development of New Drilling Fluid Systems
- Use of Annular Pressure While Drilling Tools
- Use of Rotary Steerable Systems
- Monitoring of Downhole Vibrations

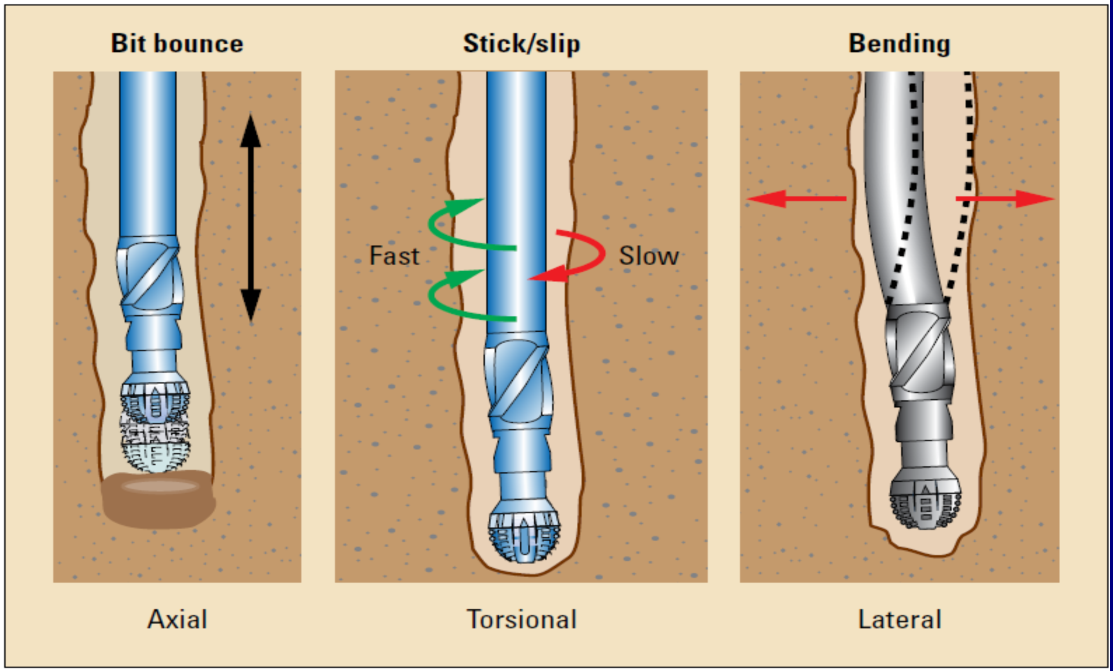
Development of New Drilling Fluid Systems

- Various synthetic water-based mud are being developed – to match the performance of oil-based mud
- Addition of coating/plugging materials
  - Silicates
  - Methyl Glycoside
  - Mixed-Metal-Hydroxide (MMH)

Use of Rotary Steerable Systems

- The principle value of a rotary steerable system (RSS) is to allow continuous rotation while steering. Major benefits are:
  - Improved drilling efficiency
  - Optimized hole quality (gauged and smooth well path)
  - Reduced risk of stuck pipe

Monitoring of Downhole Vibrations



- Vibrations result from complex interplay of factors – deviation, BHA design/components, bit type, poor hole conditions
- 3 major vibration types – axial, torsional, & lateral – all can lead to wellbore instability

Monitoring of Downhole Vibrations

Mode of Vibration	Real-Time Diagnosis	Typical Environment	Potential Cure	Other Solutions
Axial shocks	Topdrive or kelly shaking, downhole shocks	Hard formations, vertical holes, roller cone bits	STOP—Change WOB and change rpm	Change to less-aggressive bit, use a shock sub
Bit whirl	LWD caliper shows overgauge hole but bit is undergauge	Aggressive side-cutting bit	STOP—Increase WOB and decrease rpm	Change bit, use full-gauge NB stabilizer
BHA whirl	Large downhole shocks, increased STOR	Washed out hole, BHA pendulum or unstabilized	STOP—Increase WOB and reduce rpm	Use a stiffer BHA
Stick/slip	Large surface torque and rpm fluctuations, MWD peak-peak rpm	Aggressive PDC bits, high wellbore BHA friction	STOP—Reduce WOB and increase rpm	Increase mud lubricity, use less-aggressive bit, improve hole cleaning

Case Studies

Case Study - 1

- Location: Asabo Field, Nigeria
- Wellbore Instability Related Problems
  – Stuck Pipe
  – Excessive torque and drag
  – Pack-offs
  – Inability to log the well

Remedial Actions - Case Study 1

- **R**educed pressure fluctuations (trip wisely)
- Controlled mud weight
- Reduced drill string vibrations
- Excellent supervision – monitored trend changes (torque, drag, fills during trips, & volume of cuttings)

Case Study 2

- **Location:** Valhall Field , Norway
- **Wellbore Instability Related Problems**
  - Hole packed-offs
  - Stuck pipe
  - Tools lost in hole
  - Sidetracking
  - Inability to land casing

Remedial Actions - Case Study 2

- **Used Integrated Approach**
  - –Constructed geomechanical earth model
  - –Monitored drilling data, acquired more data, & updated model
  - –Interpreted observations
  - –Changed hole inclination and azimuth

Summary and Conclusions

Remember!

Although we can’t control what the drillers do, we can influence them and gain credibility with them by understanding their problems, speaking their language, and letting them understand the consequences of their actions.

Summary

- Combined analysis (integrated approach) of wellbore stresses, mud chemistry, and excellent drilling practices is the key to minimizing wellbore instability
- With adequate planning and supervision the problems can be solved if not totally eliminated.

Summary

- Total prevention of wellbore instability is unrealistic.
- Wellbore wants to collapse
- **Three main causes of wellbore instability**: Mechanical; Chemical; Drilling Practices
- Prevent pressure surges/swabs
- Maintain correct mud weight (Increase mud weight at higher hole angles)
- Minimize time hole is open
- Maintain good mud inhibition
- **Warning signs**: Torque & drag increase; Ledges; Bit balling; Soft cuttings; More caving; Increased mud viscosity and low gravity solids

Conclusions

Before Drilling

1. Mechanical Earth Model must be utilized to predict wellbore instability problems in an upcoming well.
2. We must anticipate remedial actions to be used, which depend on type of instability and its severity

While Drilling

3. We must employ the best drilling practices (e.g. reduction of surge/swab pressures and drillstring vibrations) as well as excellent mud chemistry

Conclusions

<u>While Drilling</u>

4. ROP and hole cleaning efficiency form the key links between wellbore instability and operations. Hence, we must optimize hole cleaning and minimize open hole time
5. Must perform continuous caving analysis and control surface parameters

<u>After Drilling</u>

6. Perform Post-Drilling Review – collect data and update MEM); detail wellbore instability events

<u>Key words</u> – Planning, Teamwork & Excellent Drilling Practices/Supervision

I would like to thanks to the following:

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- Mewbourne School of Petroleum and Geological Engineering, The University of Oklahoma for permission to take part in this important event