AAPG Webinar on Complex Well Guidance

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Thursday, January 28, 2010

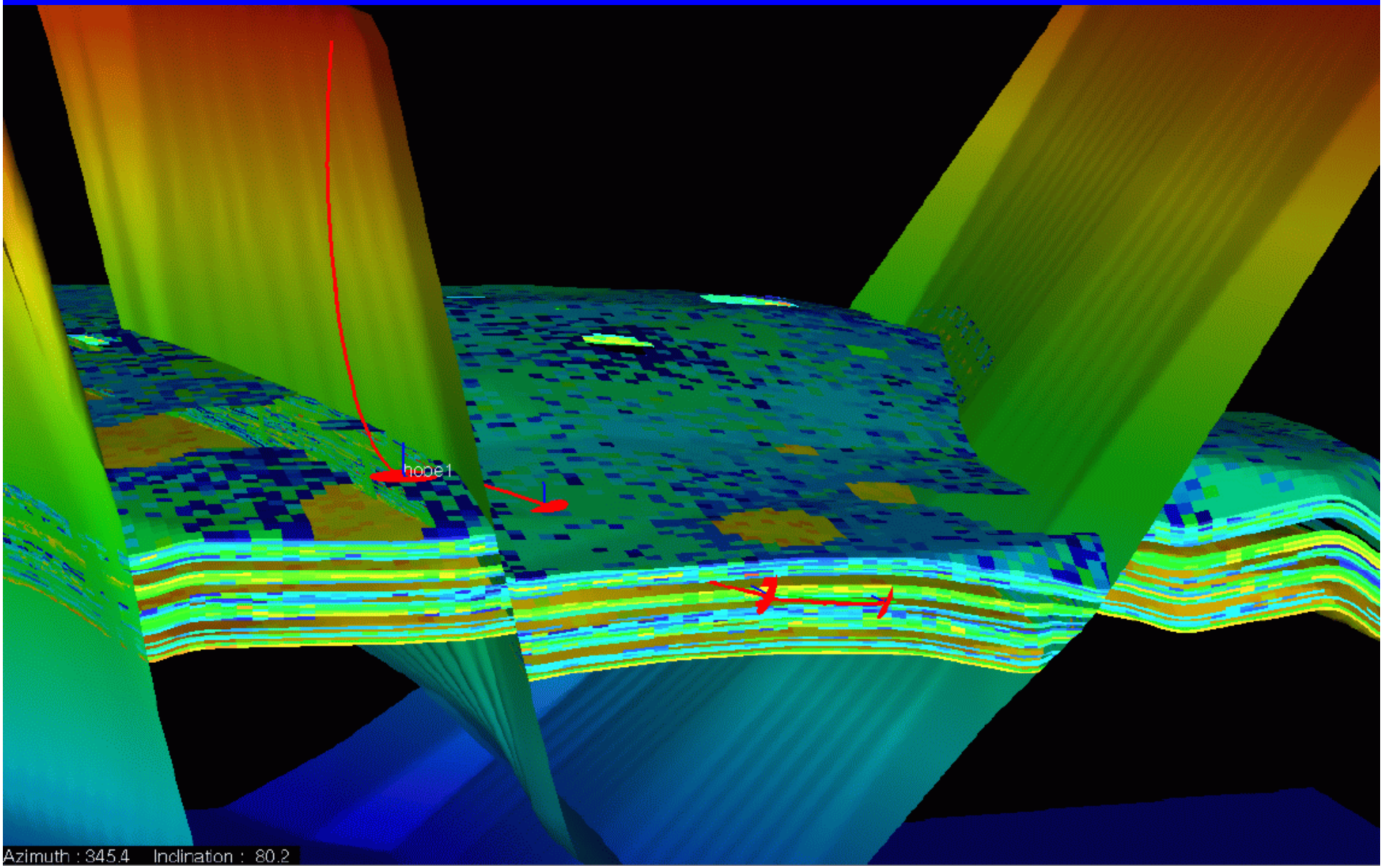
Background and Plan

- Guidance; Taken from Chapter 6 of the Complex Well Core Competency, (CWCC), 5-day asset team cross-training program on horizontal well exploitation.
- To address “guidance”, we first must assume you have a core competency understanding of the basics of directional drilling, horizontal well profile design, and Geo-steering, a major failure mode, even in “Resource” plays.
- A quick review of the first 2 will be conducted
- Will deliver as much as possible in 45 minutes, then 15 minute Q&A.

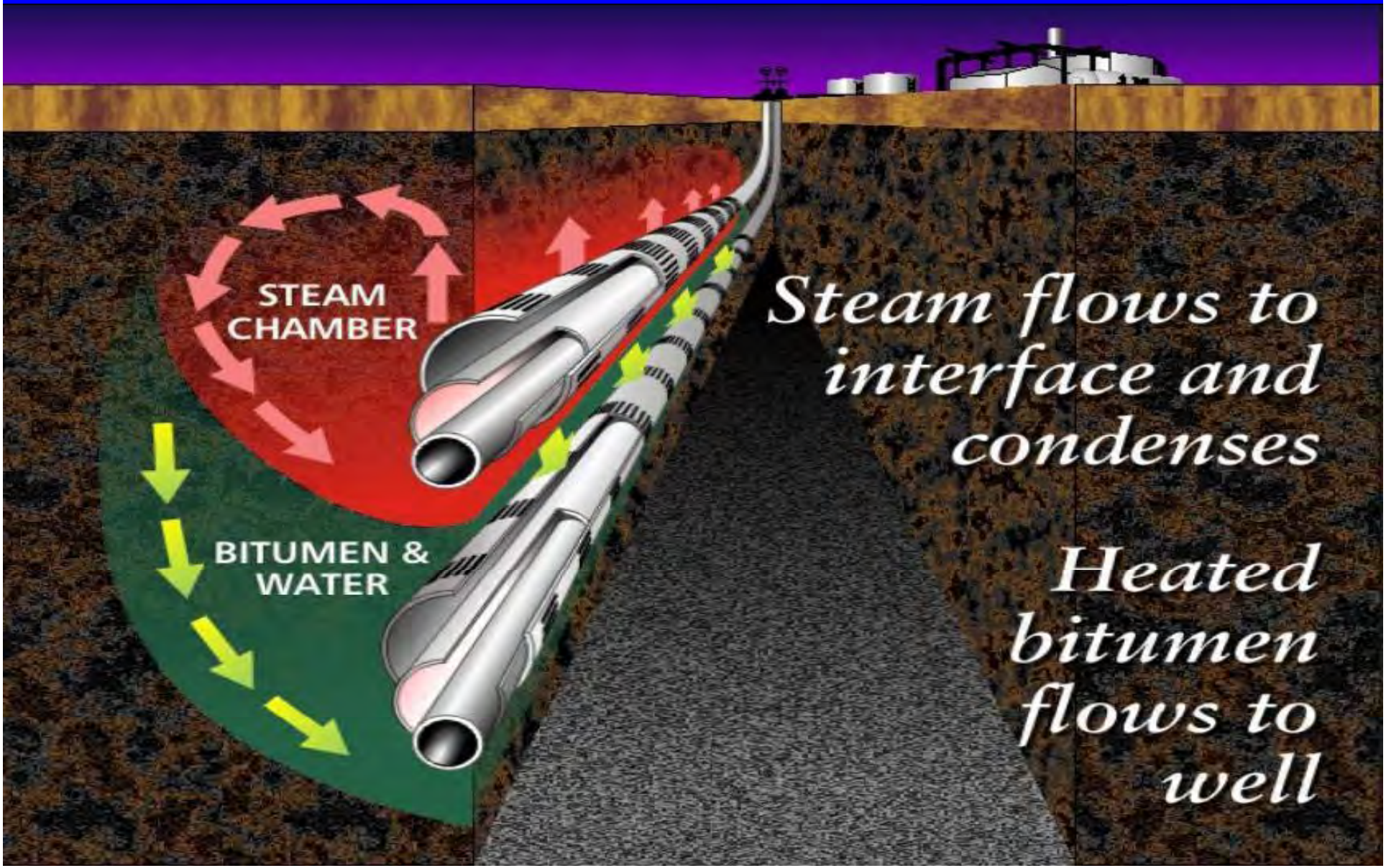
1st- Well Profile Design

- Optimized h-wells must be designed back-to-front with a site-specific multidiscipline team working with a 3D geometric well plan = PROFILE. We then generate an artificial survey file of the planned profile to pre-engineer the well, rig requirements, hydraulic design etc.
- This is a new demand, not considered in vertical wells & is a critical element for optimized application with complex wells.
- There is no standard design, each must be site-specifically customized by the team, once drilled is fixed, & effects all life cycle capabilities & even the production process.

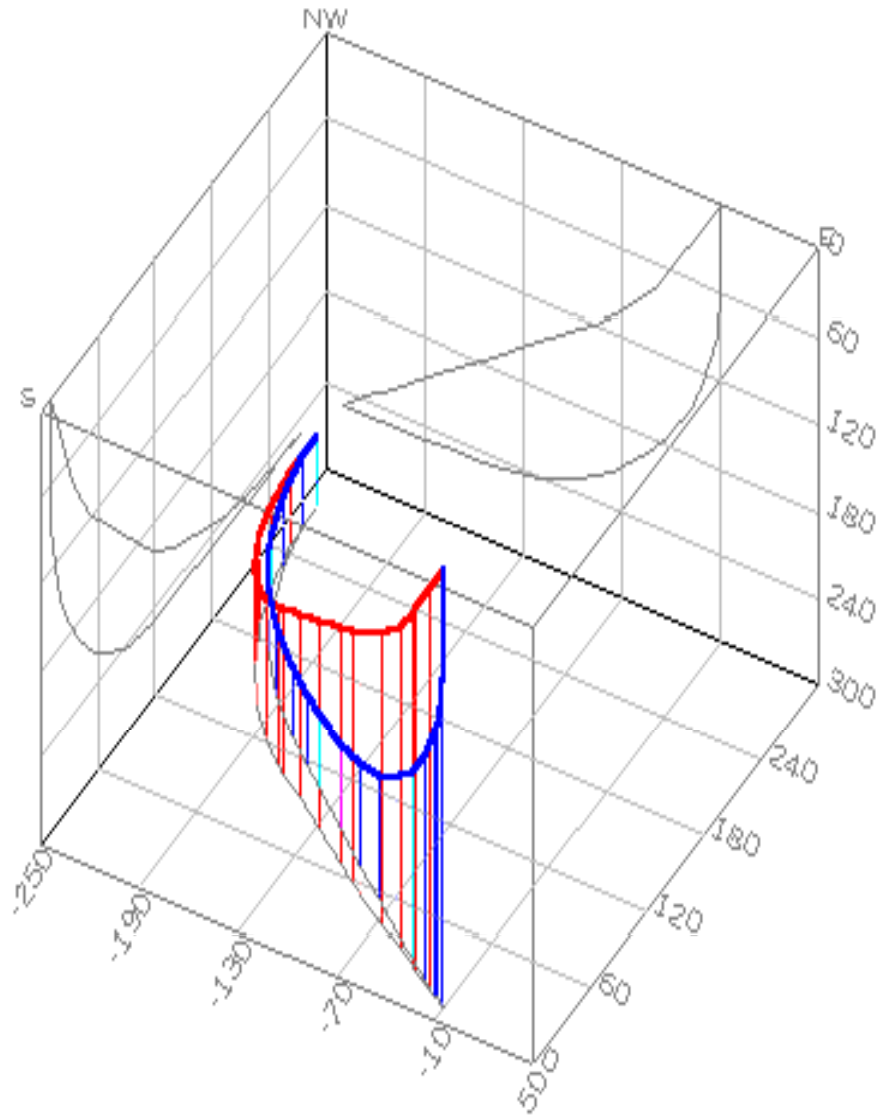
Example of 3-D design profile
with seismic interpretation, we plan geometrical, then drill
Geologically, thus Geo-steering, a major failure mode



SAGD (Steam Assisted Gravity Drainage) Process
Accurate guidance is critical to success of the sub-cool process in SAGD

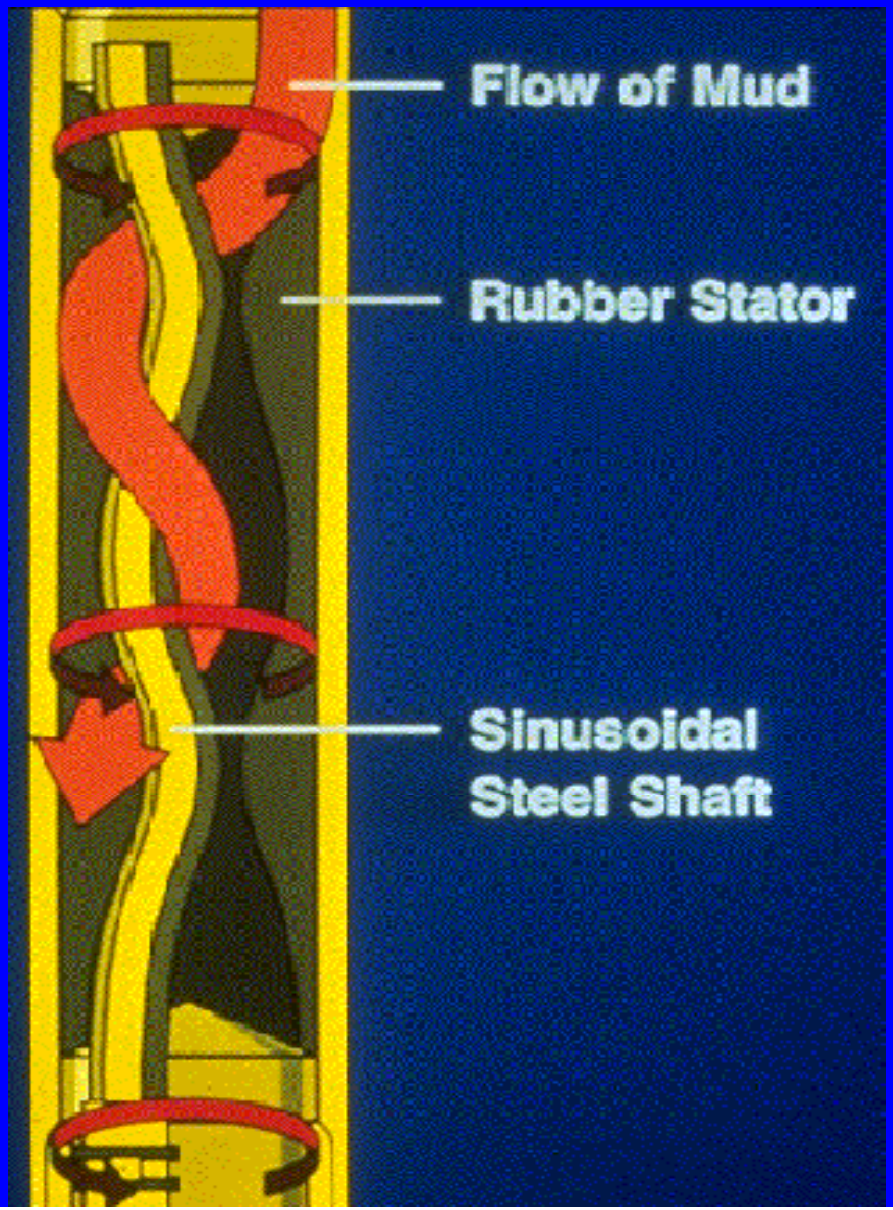


Artificial survey file and 3-D IMAGE SLANT & CURVE Profile DESIGN, all the team should review this to confirm the planned profile design meets all long term production objectives



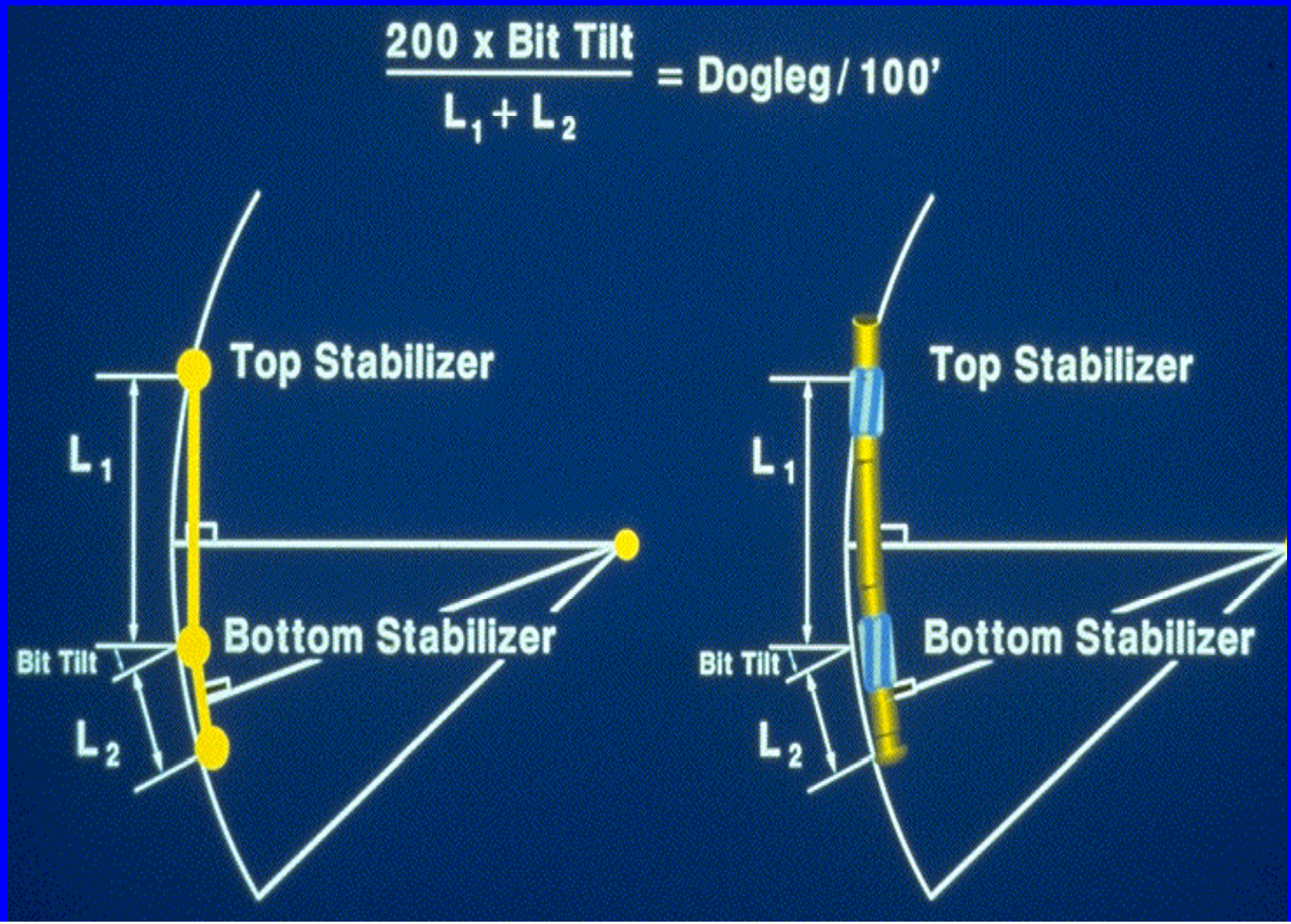
2nd; Basic Directional Drilling with a Positive Displacement Motor,

Sorry to cover the basics, but all must understand concept of the ability to spin the bit with-out drill-string rotation, the "slide" mode.

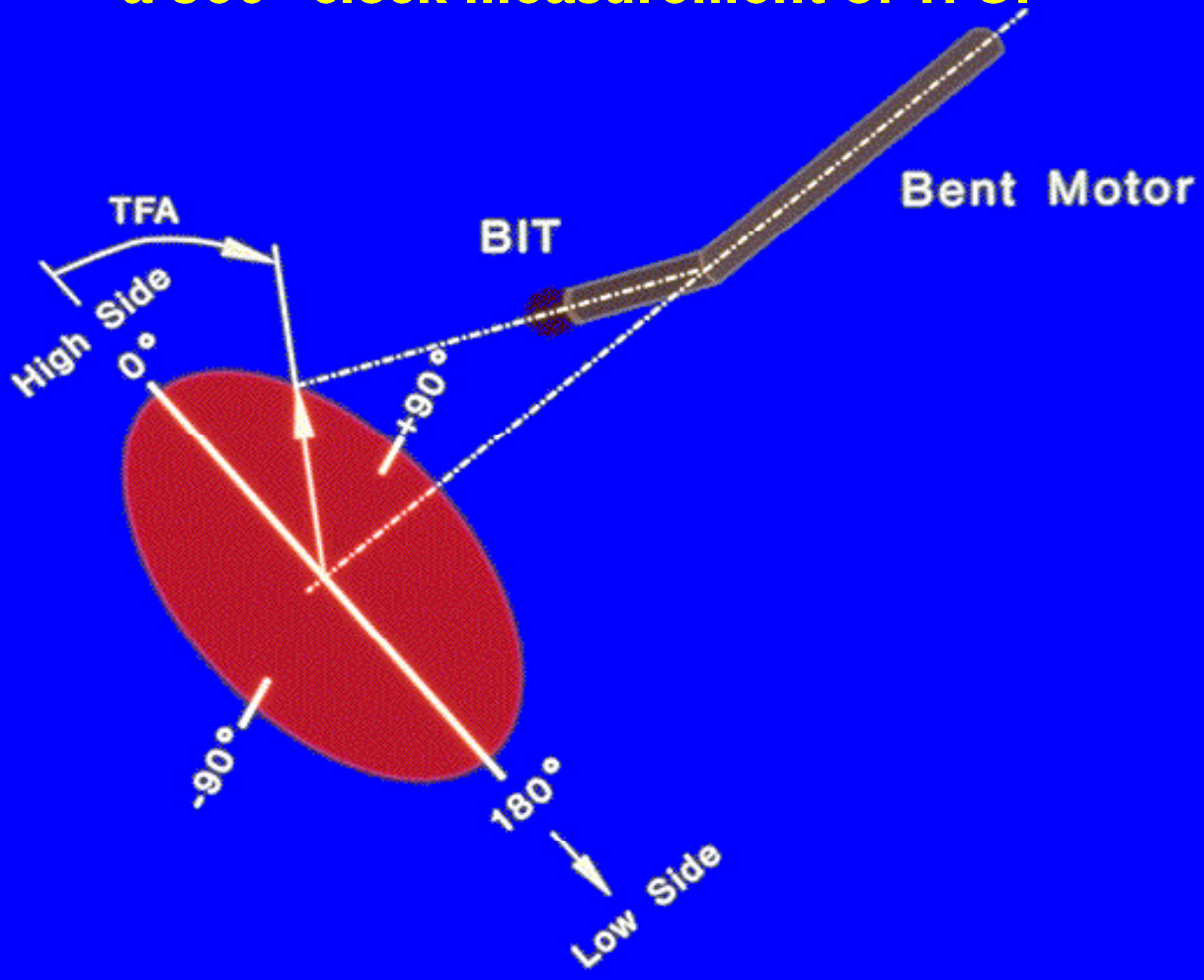


Stabilized Motor, 3 - Point Geometry

All conventional directional motors work this way, three points describing an arc, if drilled in the slide mode, bit would "tend" to drill in the plane of the TFO at a build rate of x° per 100' of length drilled

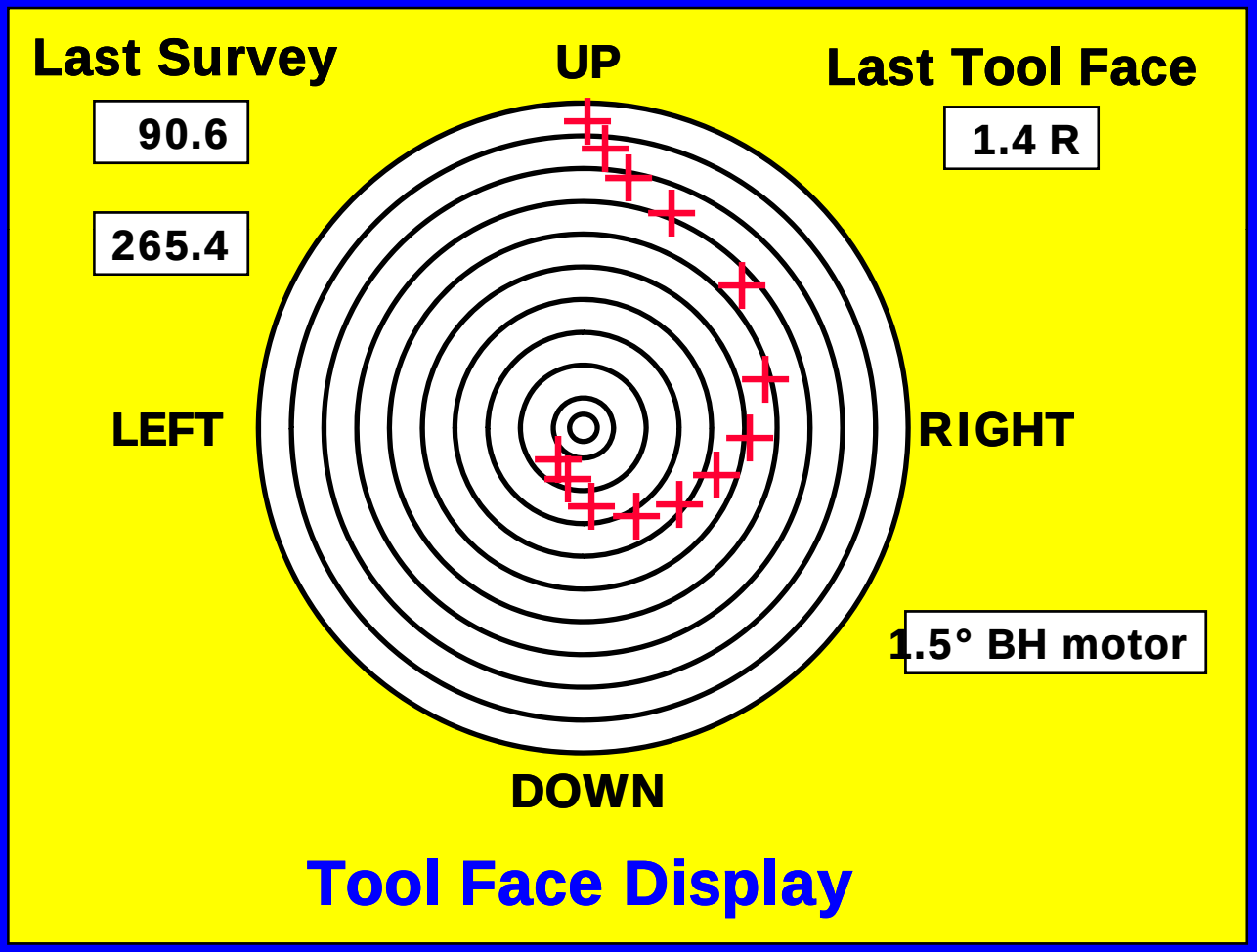


Tool Face Orientation (TFO); bit is orientated by slow surface rotation, to the plane (direction) desired, then drilling progress with no pipe rotation in the slide mode, thus giving 3-D control of the well path, would always want a 360° clock measurement of TFO.



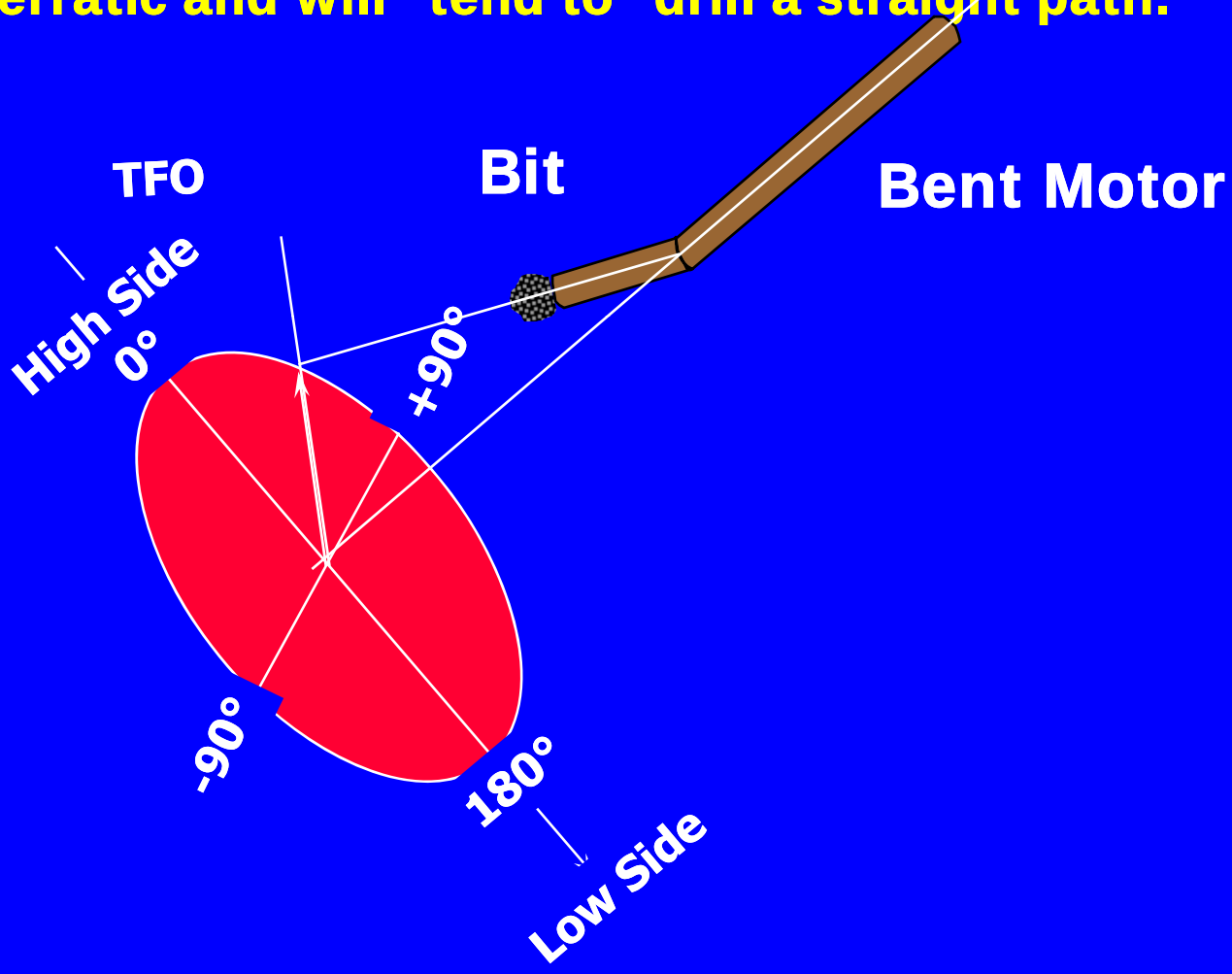
MWD Operations - Tool Face

Orientating the TFO to the High Side to start a “slide” section to build angle.



Tool Face Orientation (TFO)

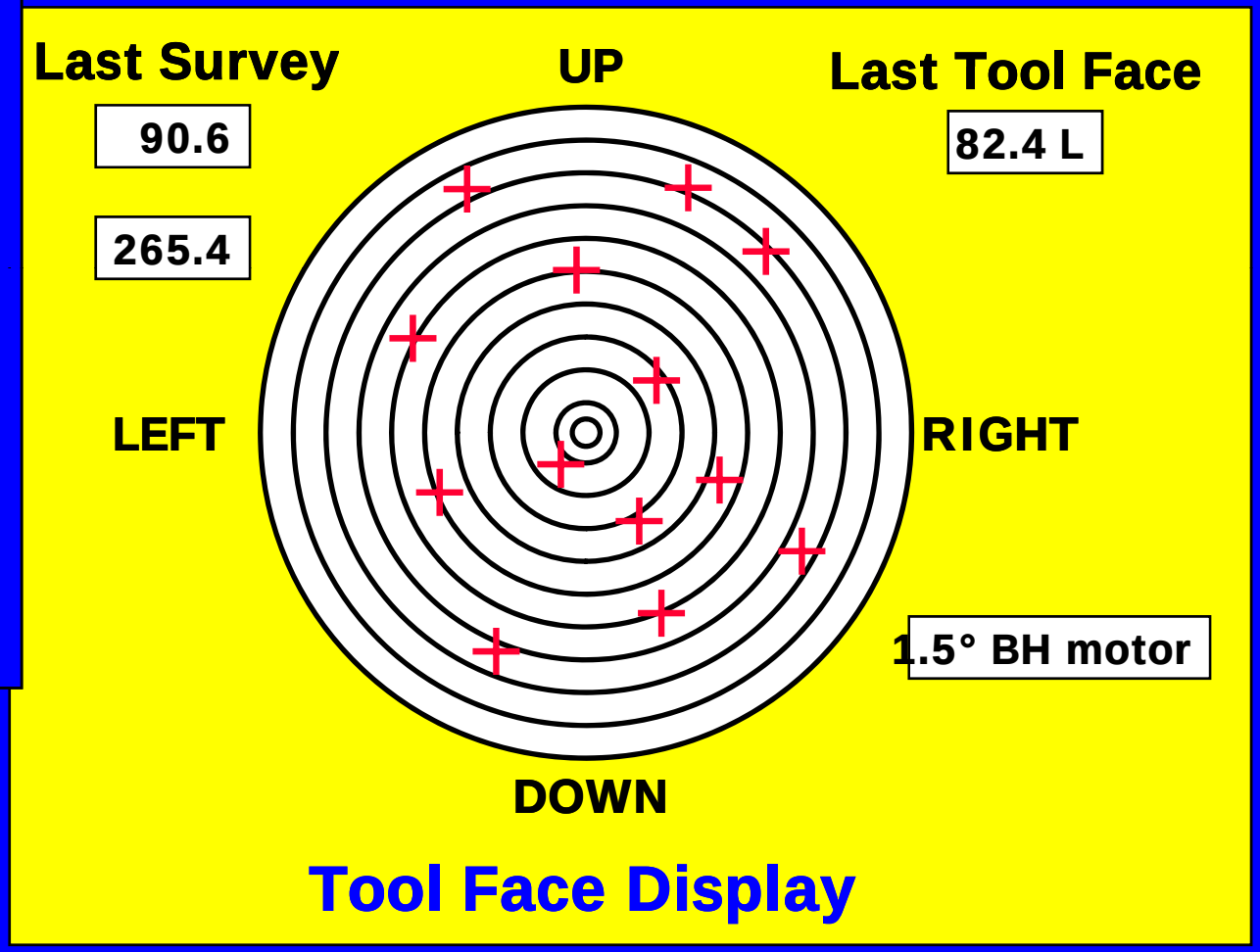
By pointing the bit in desired direction, will tend to build at design 3-point geometry in slide mode, but when rotating at surface, TFO is erratic and will "tend to" drill a straight path.



MWD Operations - Tool Face

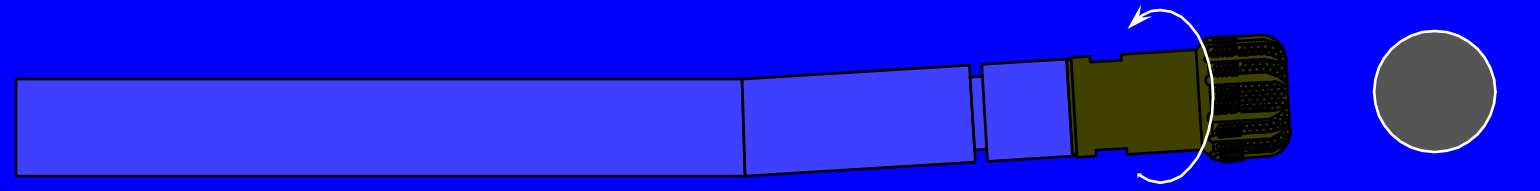
Example of surface reading of TFO in rotary mode.

The driller will always prefer the rotary mode, gives more ROP, better hole, less destructive, less risk of sticking etc.

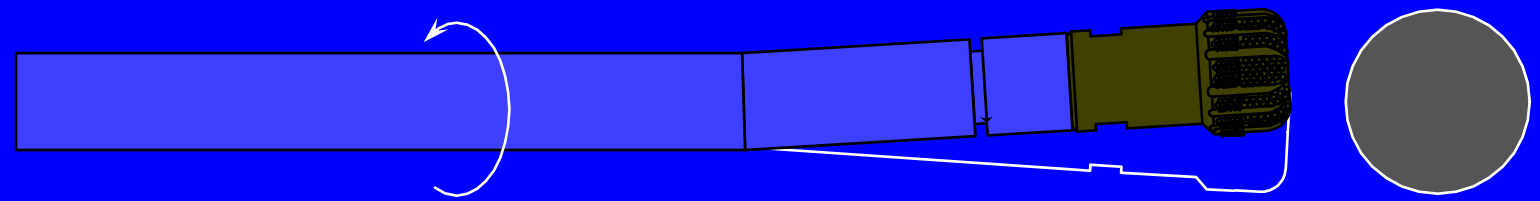


Oriented vs. Rotated Motor Drilling

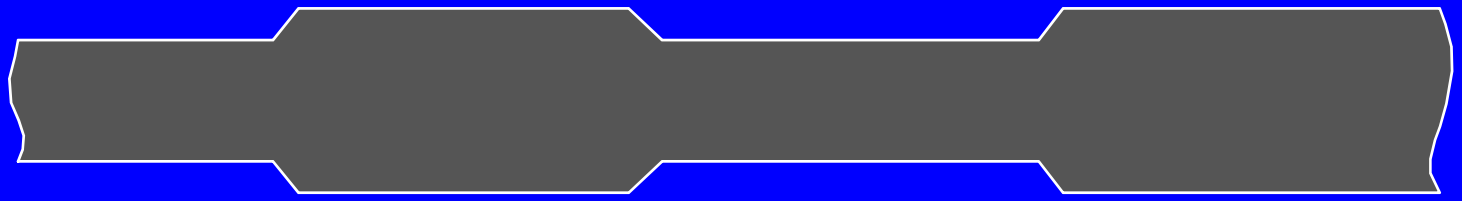
All conventional directional drilling done by combinations of slide to make course corrections, and rotary mode to drill straight, each turn adds T&D, thus limiting the number of course corrections available in any site-specific setting, a key aspect to successful Geo-steering



Hole size



Oriented **Rotated** **Oriented** **Rotated**



not to scale

Hole Enlargement

Reality of DD Capability ☼

- Projected build rate is based on three point Geometry of BHA
- Actual build rate is controlled by drilling parameters and site-specific rock properties & are somewhat unpredictable without specific field experience
- The well profile plan must include contingencies and flexibility for both build rate & geo. surprises!
- All changes made on the fly must respect the life-cycle well objective constraints

Profile Design versus DD versus Geo-steering objectives ☼

- How can we drill this well to best meet the objectives of everyone involved?
- If compromises are required, what can be, and what cannot be compromised.
- Start with a geometric plan for all preplanning and alter within pre-defined constraints as the geology dictates, this is the relationship between directionally drilling, profile design and geo-steering.

Chapter 6 — Guidance ☼
TERMS & Core Competencies

- MWD – Schlumberger trademark for “measurement while drilling” - Establish a line of points in 3-D space, global term for guidance
- LWDD - Standard logs or sensors – rock or drilling response
- All complex wells must employ guidance (typically MWD) to place the well in 3-D space, this is a “need”, LWD tools are run for Geo-steering, evaluation or drilling monitoring, and are a site-specific “want”, often miss-represented by the service providers, one trap of Geo-steering.

GUIDANCE VS. GEOSTEERING ☼

- GUIDANCE refers to the directional drilling tools and methods employed to define & control where the well is in 3D space.
- The most common method of measurement is MWD with mud pulse telemetry, other telemetries include, EM, Intel-pipe and the old steering tools.
- Other forms of Guidance include “Gyro” MWD, Magnetic Ranging and “seeker” technologies for relief well and intersector applications.

MWD Guidance Definitions ☼

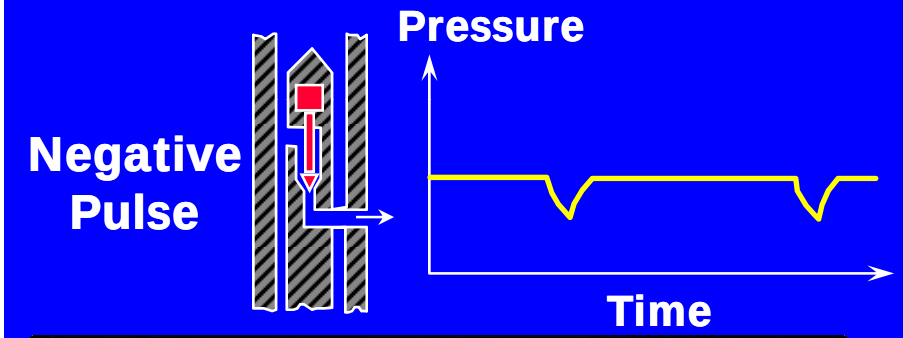
All MWD's will provide° 3, and only 3, measurements

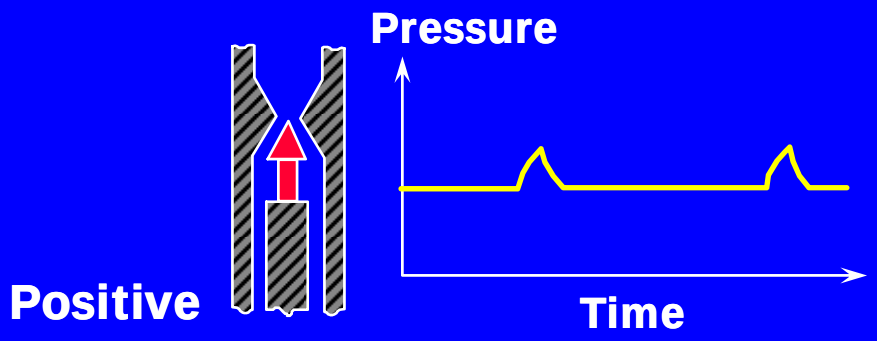
- **INCLINATION - vertical angle – measured with a Triaxial Accelerometer (measures the pull of gravity)**
- **AZIMUTH - Degrees off the North – South magnetic lines (compensated) – measure with a Triaxial Magnetometer**
- **TOOL FACE ORIENTATION - measure tool orientation – high-side or up, = 0° TFO, East = 90°, low-side or down = 180°,**

MWD ☼

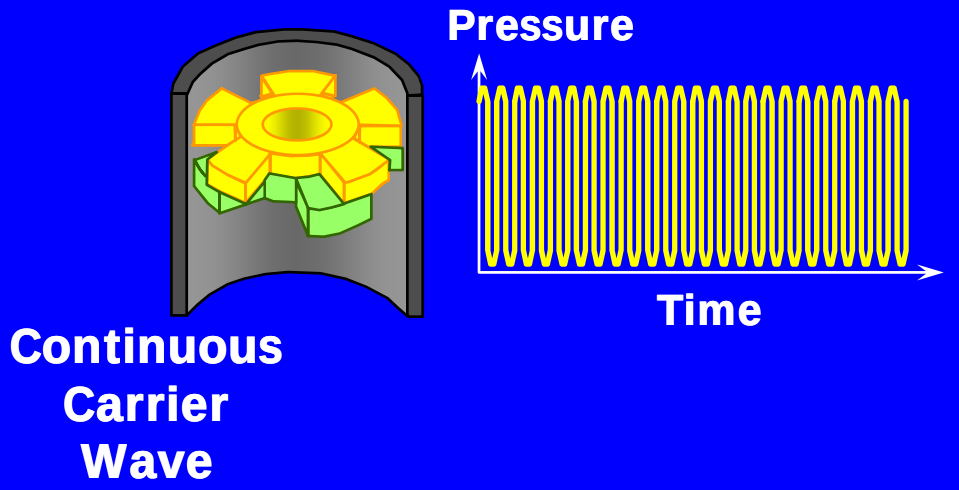
- **Fast? and efficient way to get surveys**
  - **In conjunction with motors and fixed cutters bit, can be more economic and drift tools are now used in v-well applications**
- **Subject to magnetic interference and vibration damage**
- **Electromagnetic MWD can be used in compressible fluid drilling, has less moving parts, higher baud rate and cleaner data, may replace mud-pulse in time as depth limit is overcome**

Mud Pulse Telemetries





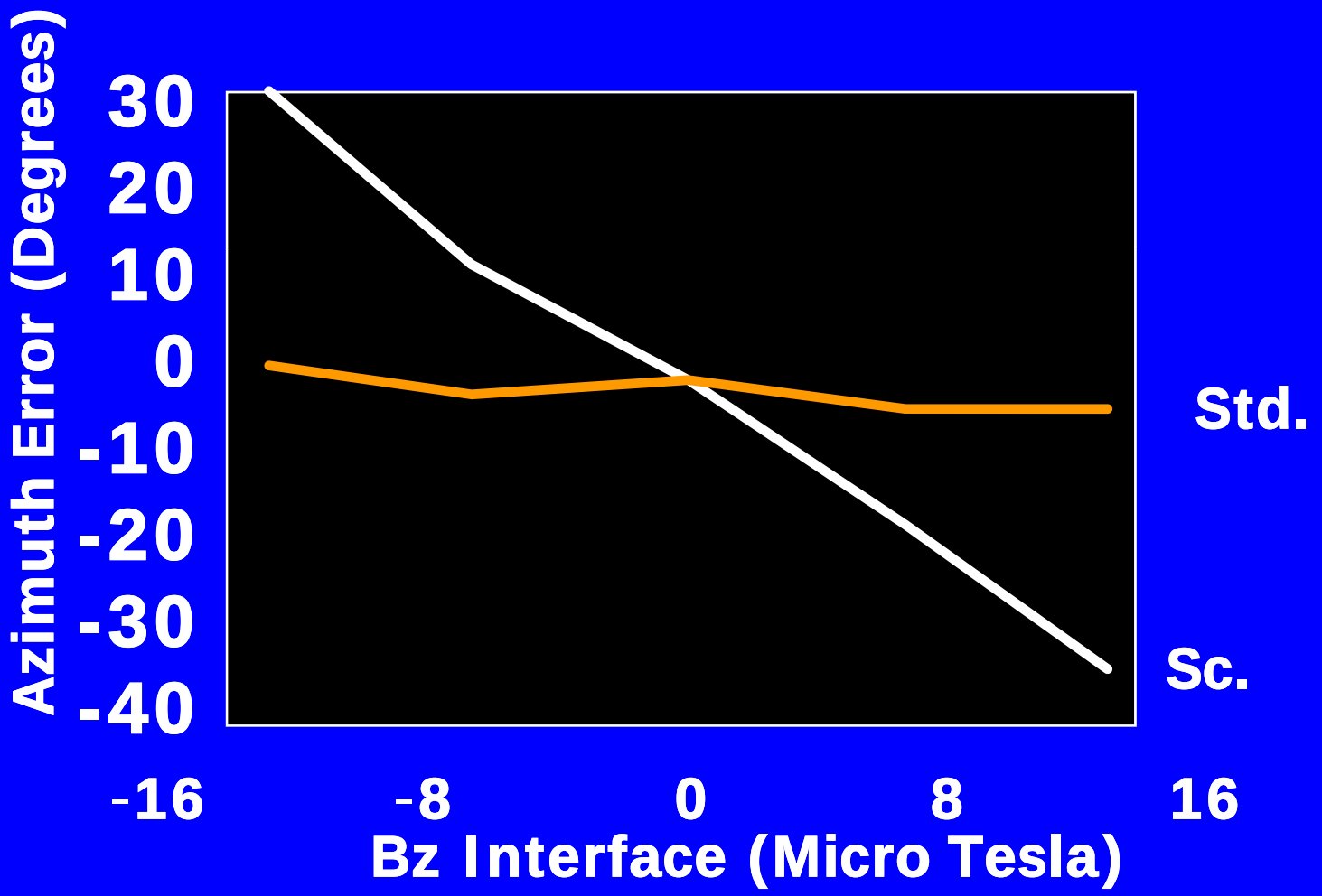
All signals travel up the inside of the pipe, heard Via a pressure transducer on the standpipe
and decoded at surface and presented to the DD
Can have 2-way communication, many different attributes in various systems



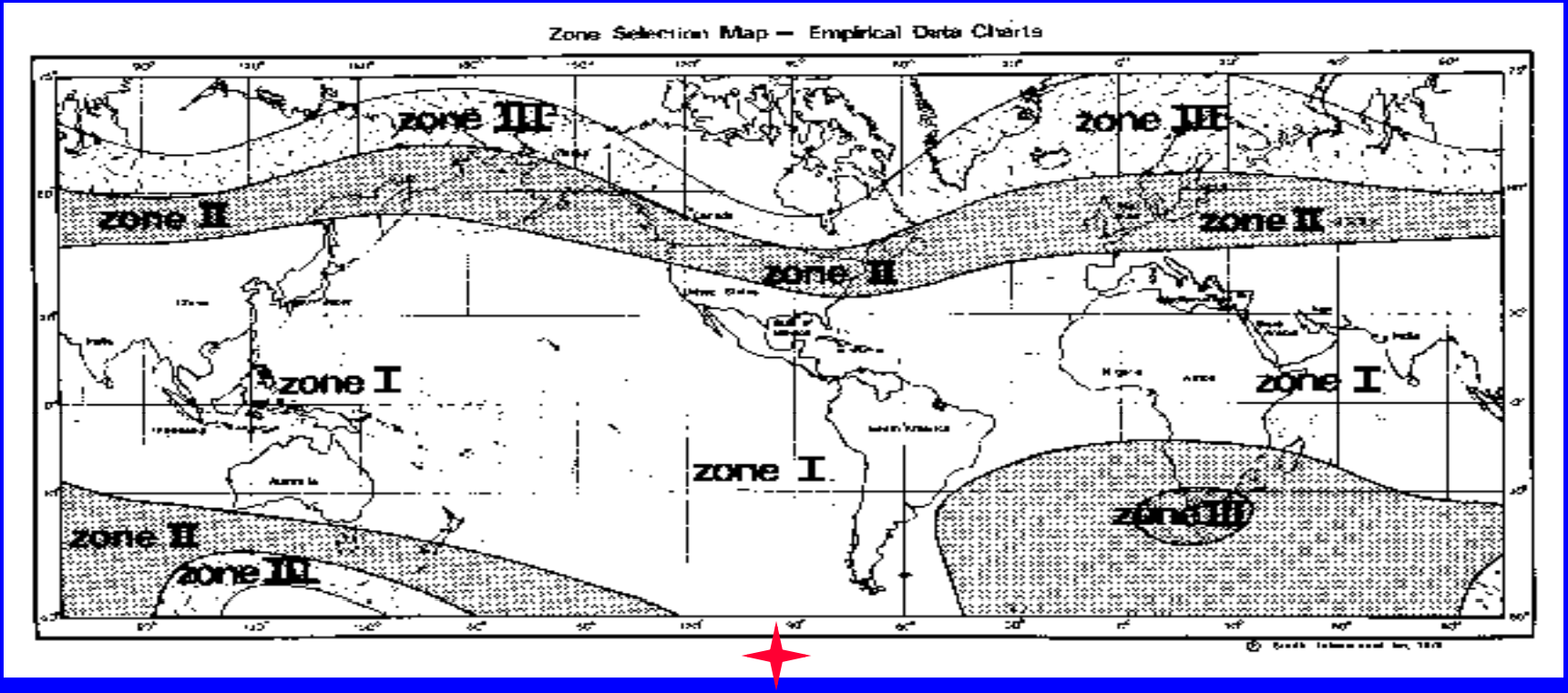
Data Transmission

- All logging tools are generally the same
- Transmit data by hard wire, magnetic waves or mud pulses
- All are binary signals (0 or 1)
- Mud pulses
  - will not work in aerated fluids
  - need pump pulsation dampeners
  - “Y” pump discharge connections
- Power supplied by batteries or a turbine, many variation of attributes and capabilities

Azimuth Error Due to EGG shape of Earth

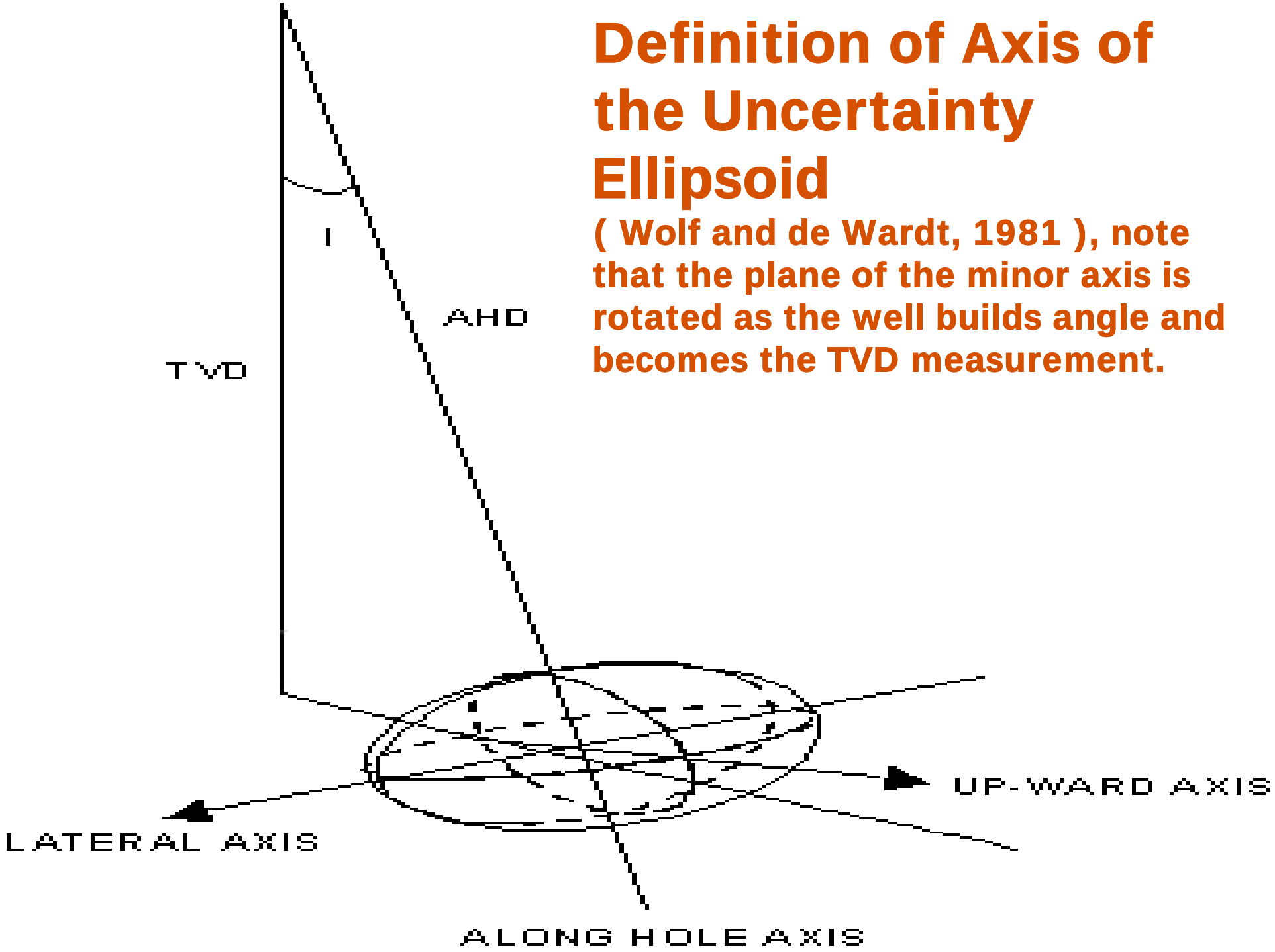


Magnetic Interference

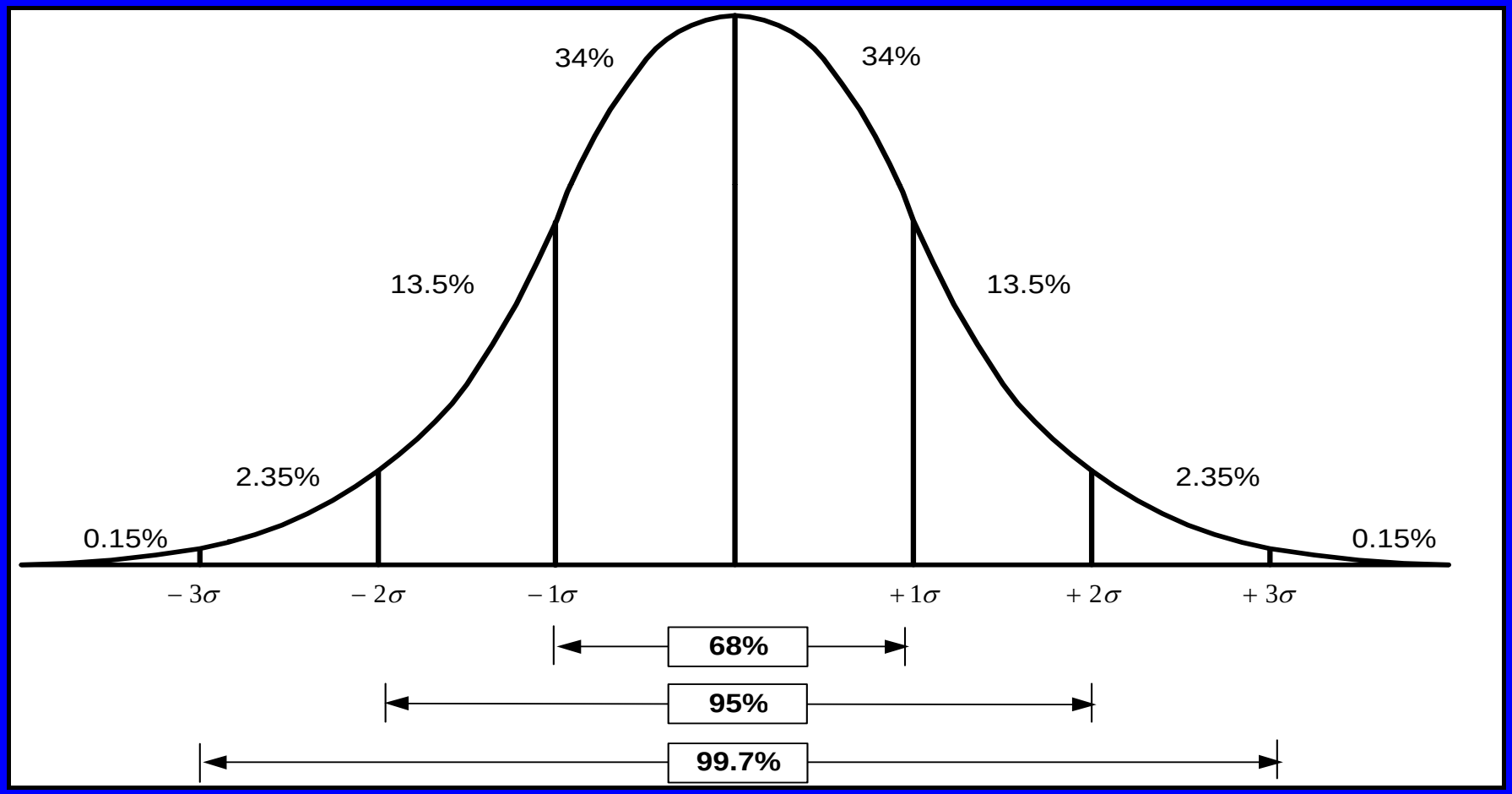


Definition of Axis of the Uncertainty Ellipsoid

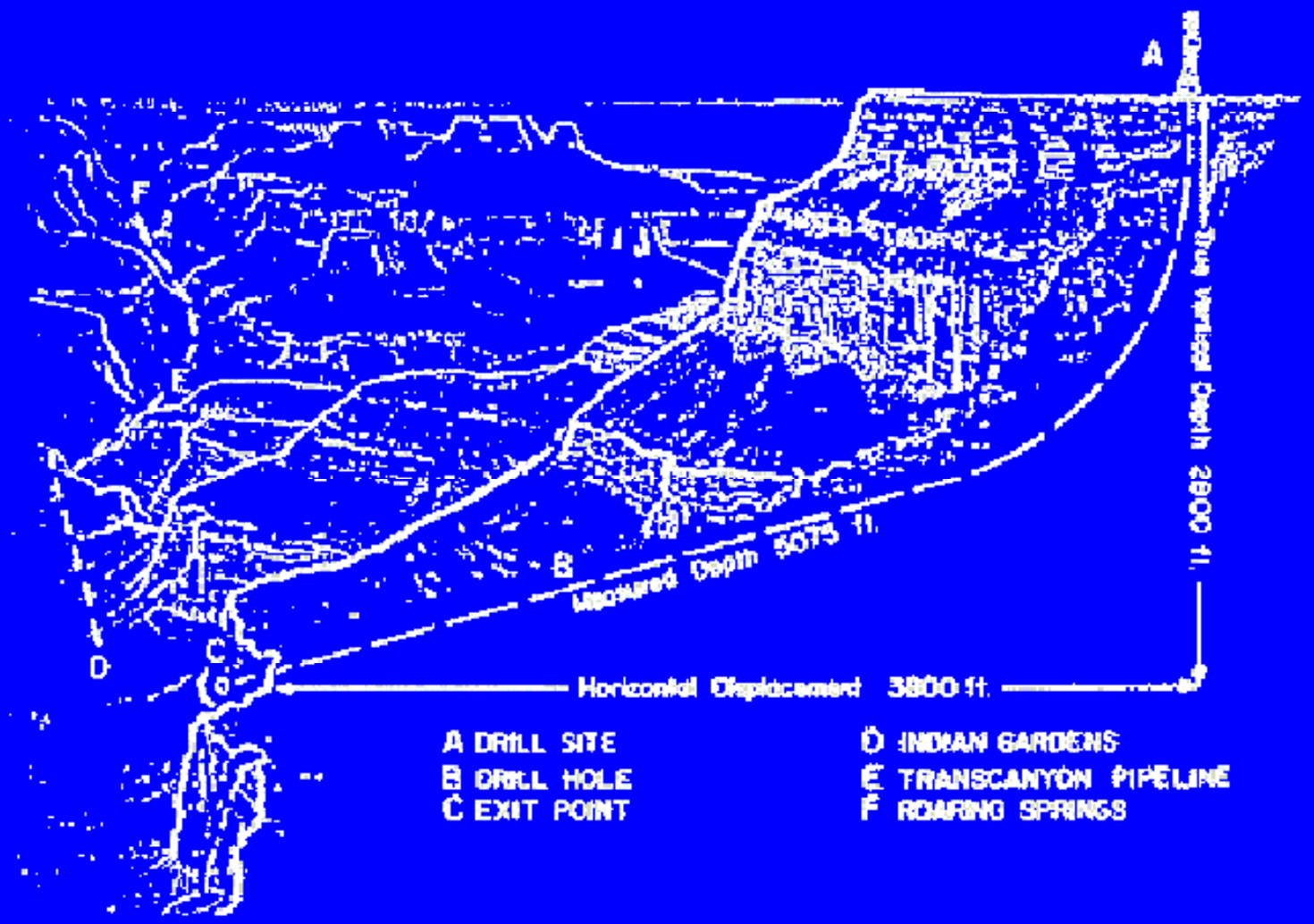
(Wolf and de Wardt, 1981), note that the plane of the minor axis is rotated as the well builds angle and becomes the TVD measurement.



Standard Deviation Distribution of the Probability of Borehole Uncertainty for a Given Axis



Grand Canyon — DOE

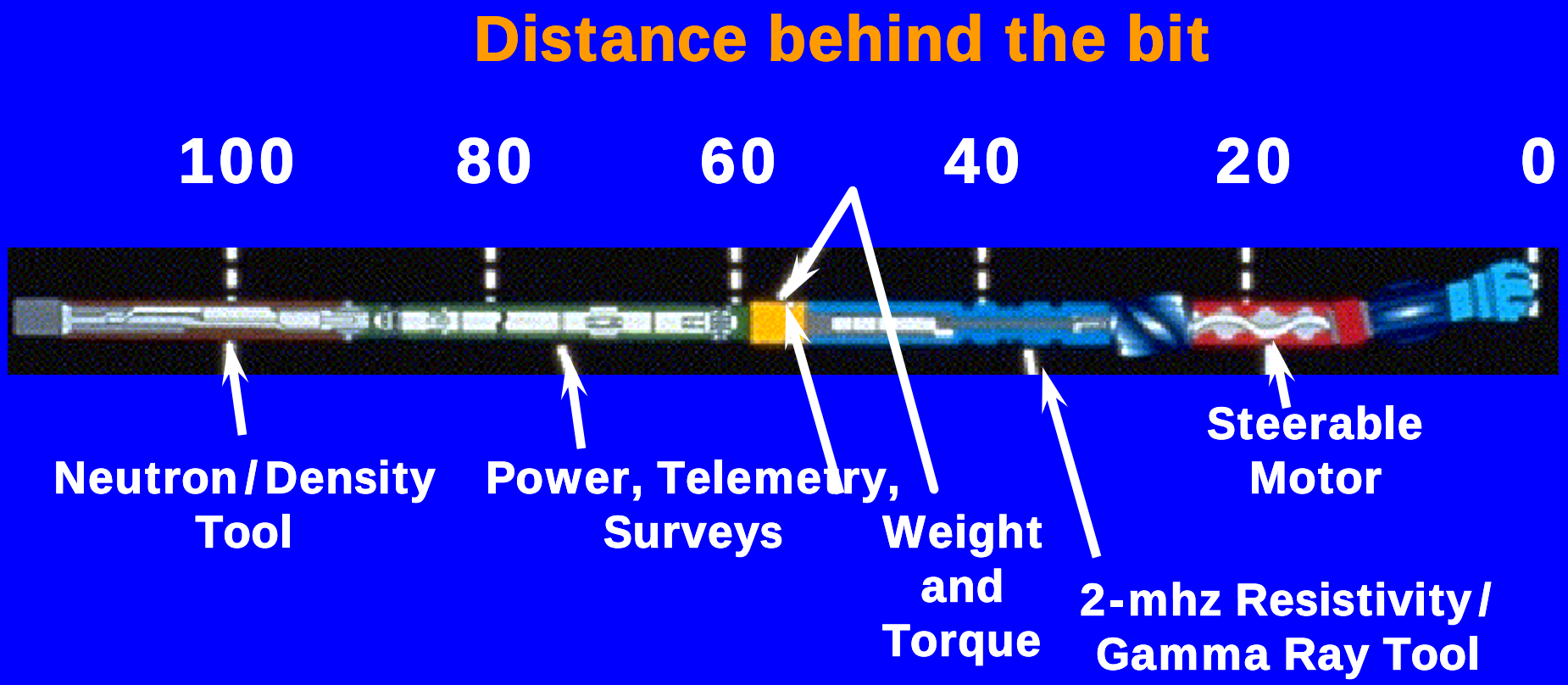


Accuracy of Different Survey Systems in TVD ☼

- With 3,000’ (1000 meters), departure from a know heel TVD. The end of well TVD is;
  - MWD = 3.5+/- meters @ TVD
  - Gyro = 2.5+/- m
  - Magnetic ranging = 1+/- m
- On a 30000' ERD well, 2-sigma position uncertainty would be in the range of 100' TVD and 500' laterally.
- But how is pipe length measured!!

Conventional MWD/LWD Directional Assembly (BHA),

Note, "needs versus wants", also, the guidance package is located 50' behind the bit, another fact that complicates Geo-steering, team must have patience in course corrections, another site-specific "art", can place some sensors "at the bit" with added telemetry.



ERD & GUIDANCE (1)

- Circa January 2009, Baker Hughes website
- An example of INTEQ's world-class work is an ERD project on Sakhalin Island in remote Eastern Russia
  - Over a dozen wells in this project have exceeded 32,808 ft (10,000 m) MD with the longest drilled to a measured depth of 38,320 ft (11,680 m).
  - Notable successes include precise positioning of the horizontal drain within a 50± cm nominal TVD target window (@#$^$#@).
  - A very misleading statement!, "the survey is not written in stone"
  - What Length Measurement, people lose pipe joints!!!

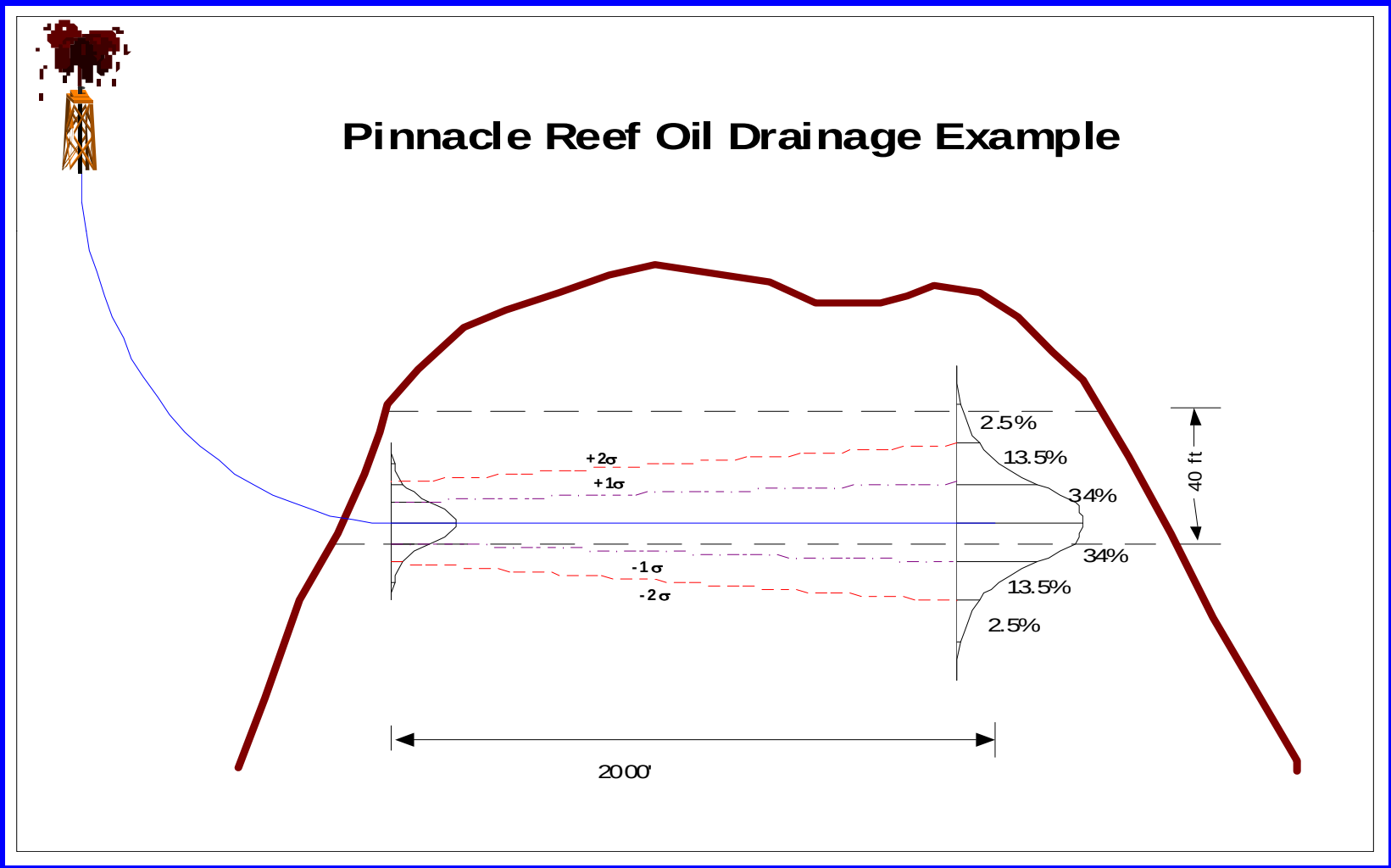
ERD & GUIDANCE (2)

- "Correcting Errors inherent in MWD Surveying", Chris Henderson, Weatherford, Beijing, World Oil January, '09
- Current running practices can introduce gross errors.
- Hole Curvature between surveys. On 93' survey intervals, using minimum curvature method, could be an error of 7.5' per K of hole length
- Can be approximated with "virtual survey" or "On the fly" surveys

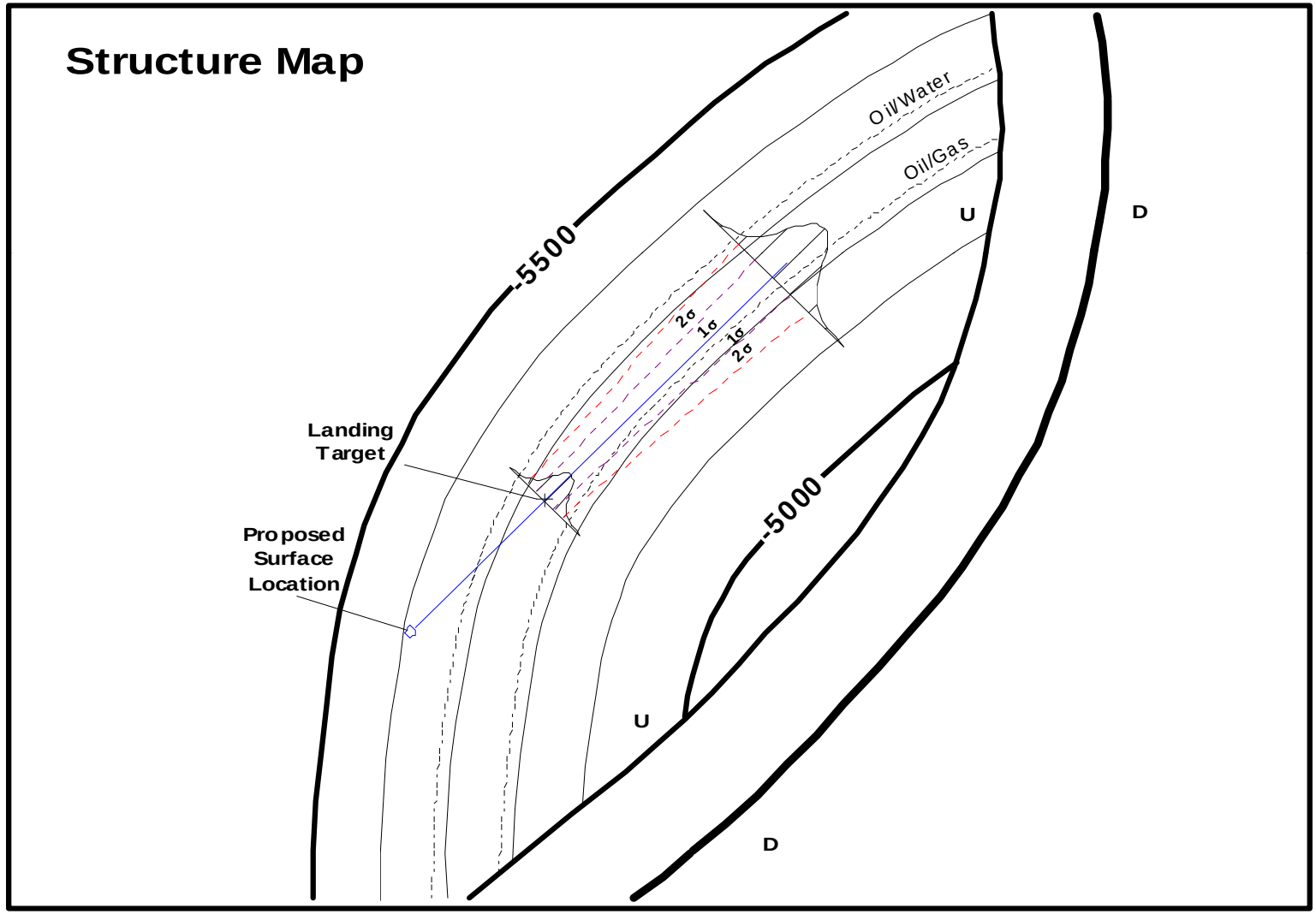
ERD & GUIDANCE (3)

- Bent Sub Effect, can alter inclination by 1° , mitigate with “cluster shot”
- Pipe Stretch, length change of around 2’ per k length.
- Axial misalignment of pipe in hole, could relate to 1' error per K length
- “I am not aware of any provider or product that handles these errors at present”
- How do we measure the length of pipe in the hole?

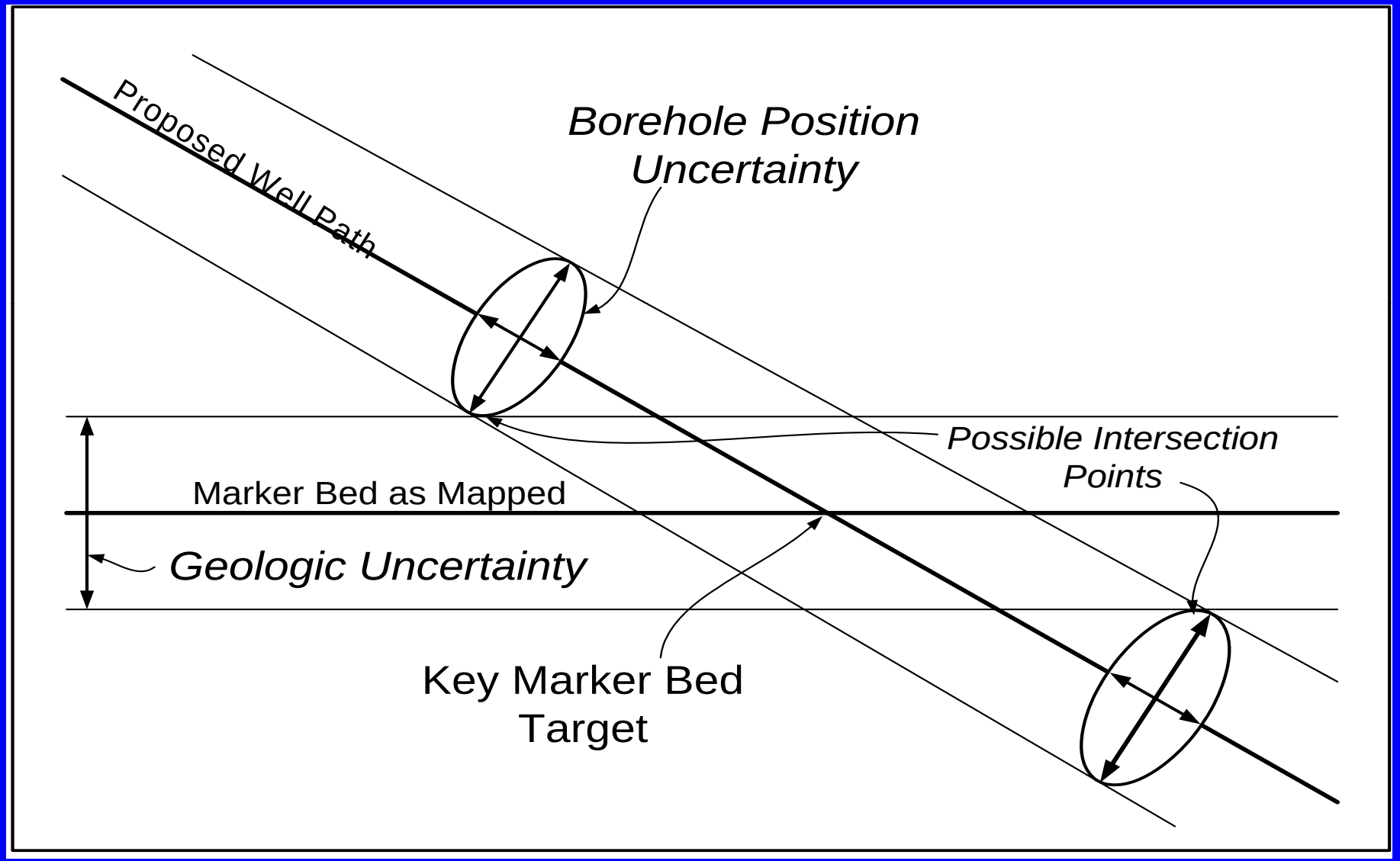
Growth and Distribution of TVD Uncertainty for the Pinnacle Reef Oil Drainage Example



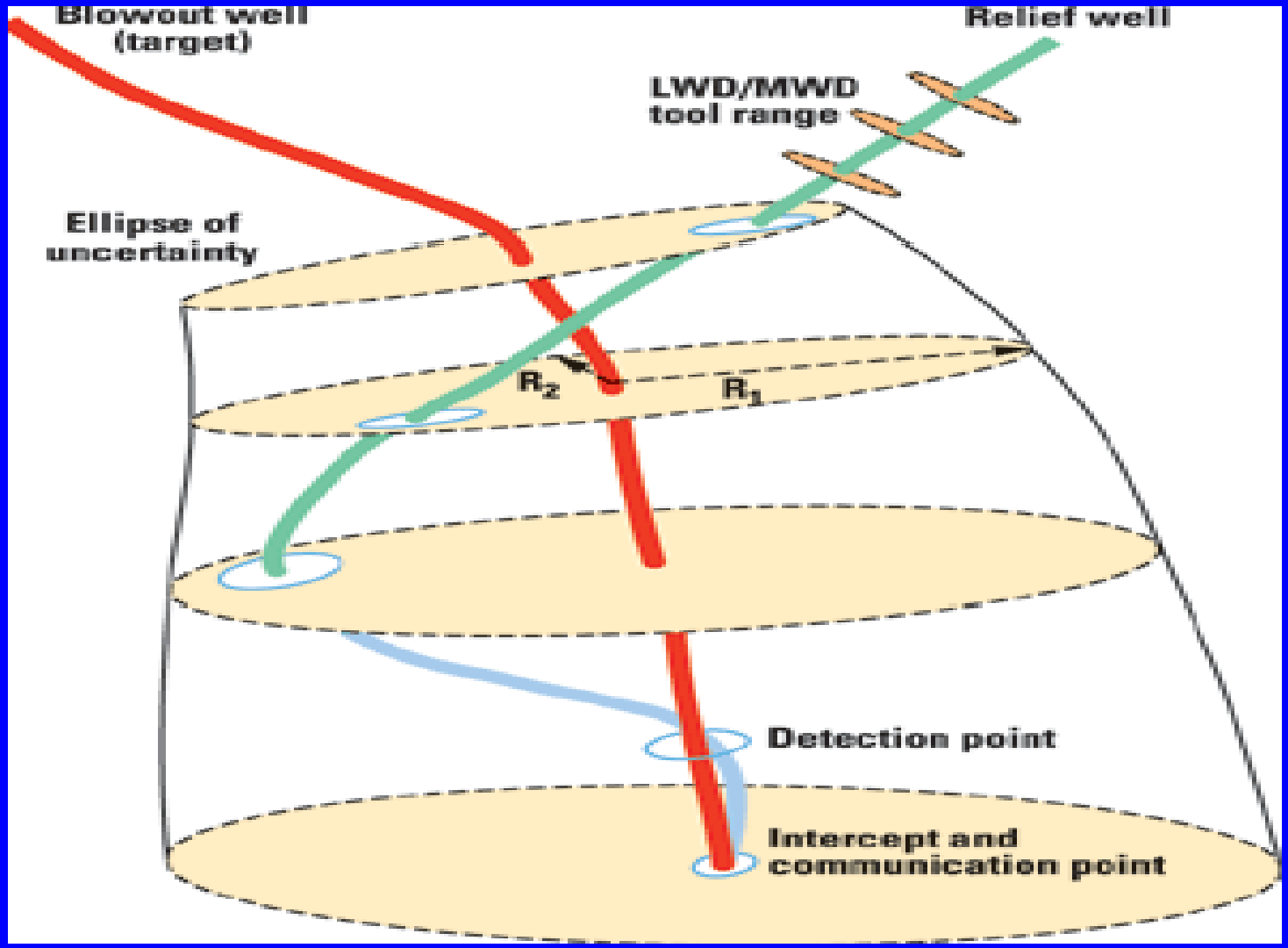
Lateral Axis of Uncertainty Growth and Distribution for a Horizontal Well Prospect to Drill along the Geologic Strike in a Steeply Dipping Fault Block



Cross-Section View Combining Geologic Uncertainty and Borehole-Position Uncertainty



LWD/MWD proximity techniques offer accelerated relief well operations , World Oil 01/'03



Update on Intersector Technology (1)

- "Connector/Conductor Wells; Multiple Wellbores with Down-hole Connections", Brunei Shell, SPE # 111411, JPT May 2008.
- November 2006, Shell drilled H-producer from onshore to intersect with deviated "conductor" well offshore. Conductor well to be top abandoned and producing through 2 completed zones above intersect point.

Update on Intersector Technology (2)

- **Good discussion on "Homing-in, or seeker" technology, after twin gyro runs on intermediate casing depth**
  - **Side-entry single-wire guidance was first used from 180 M separation, found target well was 9m north and 30 M east of survey, corrected intersector well path and continued to 45 m separation, then used "rotating-magnet" ranging system suspended in target well, found target now 1m north and 15 m east of survey, made sharp course correction then another near side-track to avoid collision, all indicators show that the 8.5" hole touched the target 7" casing.**

Guidance Uncertainty is Real

- The team must have core competency with DD, Profile, Guidance and Geo-steering if well is to be a success
- Be aware of measurement errors, particularly with pipe length
- Must roll test and calibrate tools on site
- Must have competent service providers
- If not, it is very possible you could be going in the wrong direction, a common failure mode.

AAPG and Other CWCC Staging's, 2010

April 05-09 Denver, Colorado hosted by Colorado School of Mines/PTTC
http://www.eventbrite.com/event/486497126

June 14-18 Regina, Sask. hosted by H-Tech. Petroleum Consulting
http://htech.ca/2010CWCC-Regina.doc

July 26-30 Dallas, Texas hosted by AAPG
http://www.aapg.org/education/shortcourse/details.cfm?ID=181

September 20-14,Calgary, Alberta hosted by H-Tech.
http://htech.ca/2010CWCC-Calgary.doc

November 8-12, Midland, Texas hosted by Midland College
http://www.midland.edu/~ppdc/pgtc-spring2010-listing.html#/complex

Thank You

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Thursday, January 28, 2010