Geocentric Sectoring of LWD Azimuthal Log Data for Improved RDIP and RSTRIKE Analysis: Enhanced Reservoir Navigation and Petrophysical Characterization

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ABSTRACT

We propose an improved approach for the sectoring (angular partitioning) of LWD azimuthal log data. Our technique defines the sector partitions within a geocentric system. Stratigraphic up and stratigraphic down sectors are defined such that they are perpendicular to bedding, yielding enhanced bed boundary detection and improved relative dip angle (RDIP) calculations. Likewise, stratigraphic left and right sectors are defined such that they are parallel to bedding, yielding refined relative strike (RSTRIKE) extractions for higher resolution petrophysical analysis. Initial sector settings could be pre-set from existing data (e.g., seismic data and subsurface contour maps). Azimuthal data acquired while drilling would reveal if the sectoring goes off-centered due to formational or wellbore orientation changes, allowing sectoring adjustments via downlink command to resume the geocentric sectoring.

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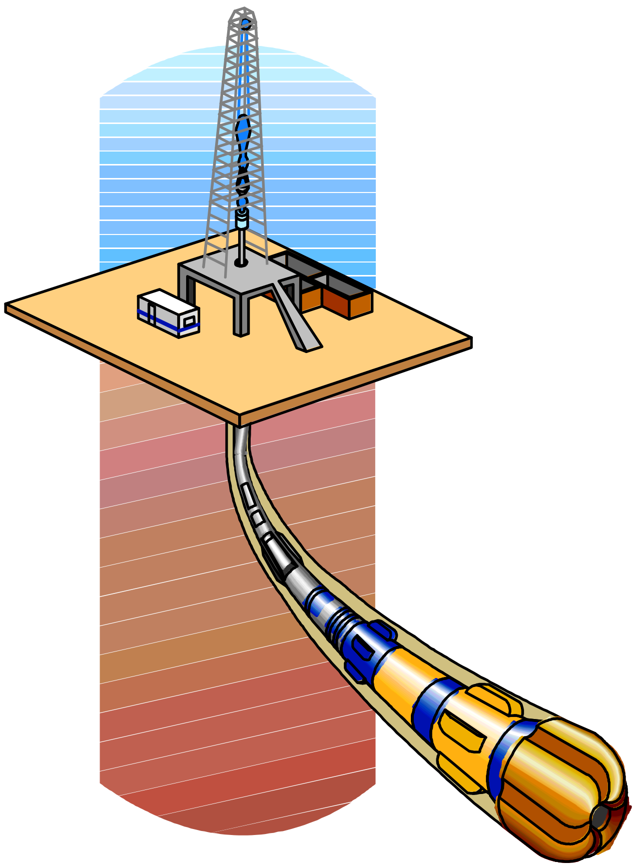
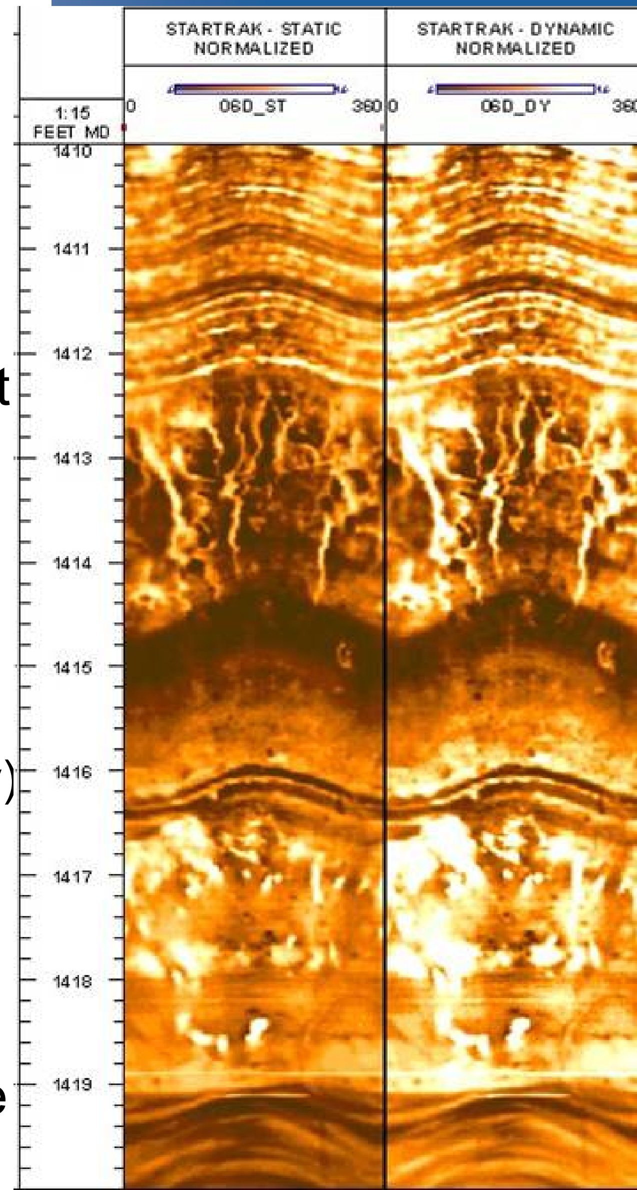
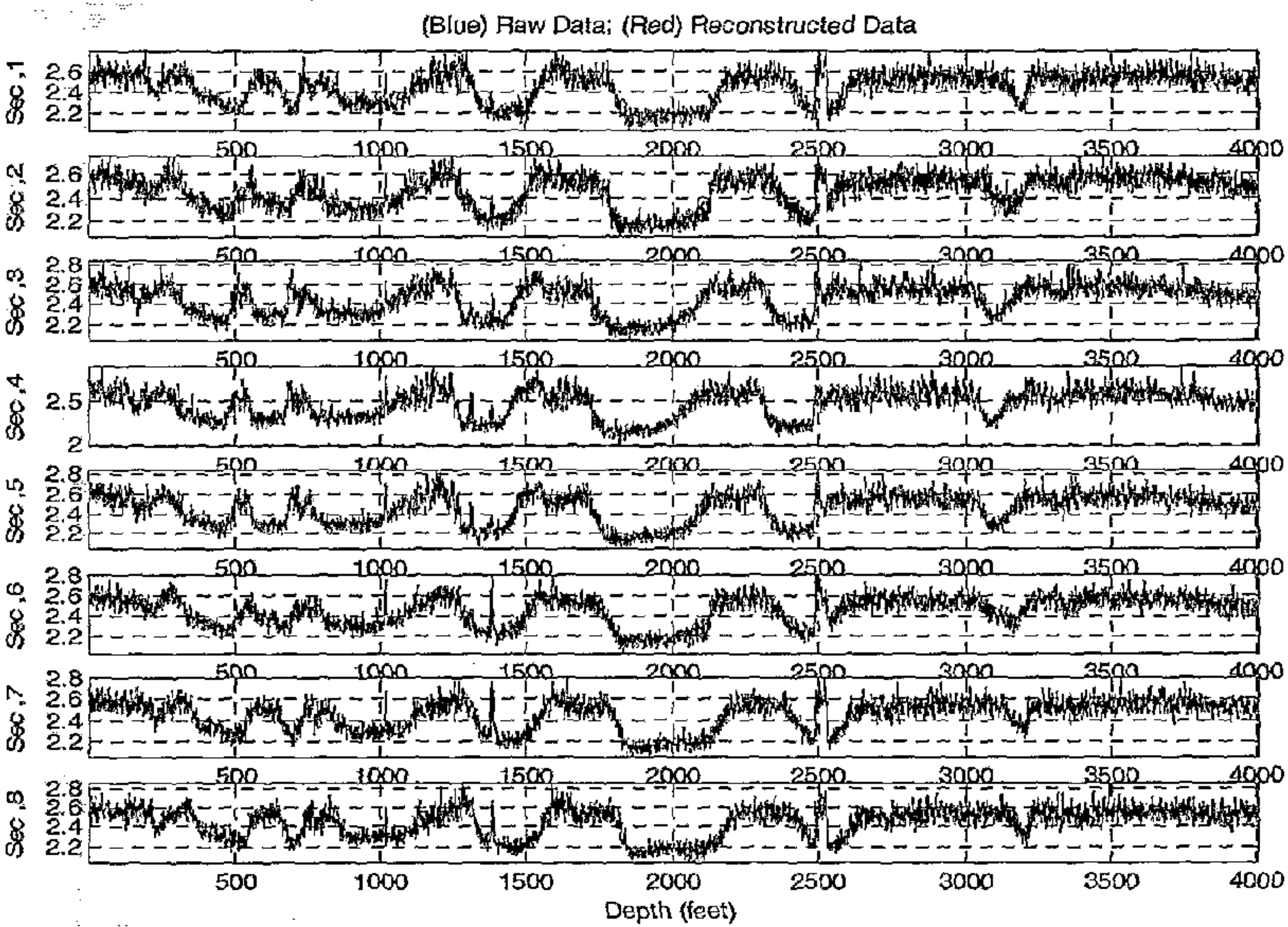


LWD Image Logs

- Sensor(s) designed for drilling
  - broad range of RPM and ROP
  - stick-slip tolerant
- <u>*Sensors rotate with drill collar*</u>, allowing for 100% borehole coverage under optimal conditions.
- LWD Image Logs now available for most key petrophysical measurements.
  - Gamma Ray
  - Azimuthal Propagation Resistivity
  - Density (rhob and delta-rho)
  - Photoelectric Effect (PE)
  - Sonic (DTcomp, DTshear, and DTstoneley)
  - Ultrasonic Acoustic
  - High-Resolution Microresistivity (e.g., StarTrak example at right)
  - Caliper
- Neutron Porosity and NMR not available due to physical limitations.



Individual Sector Curves
Azimuthal Density

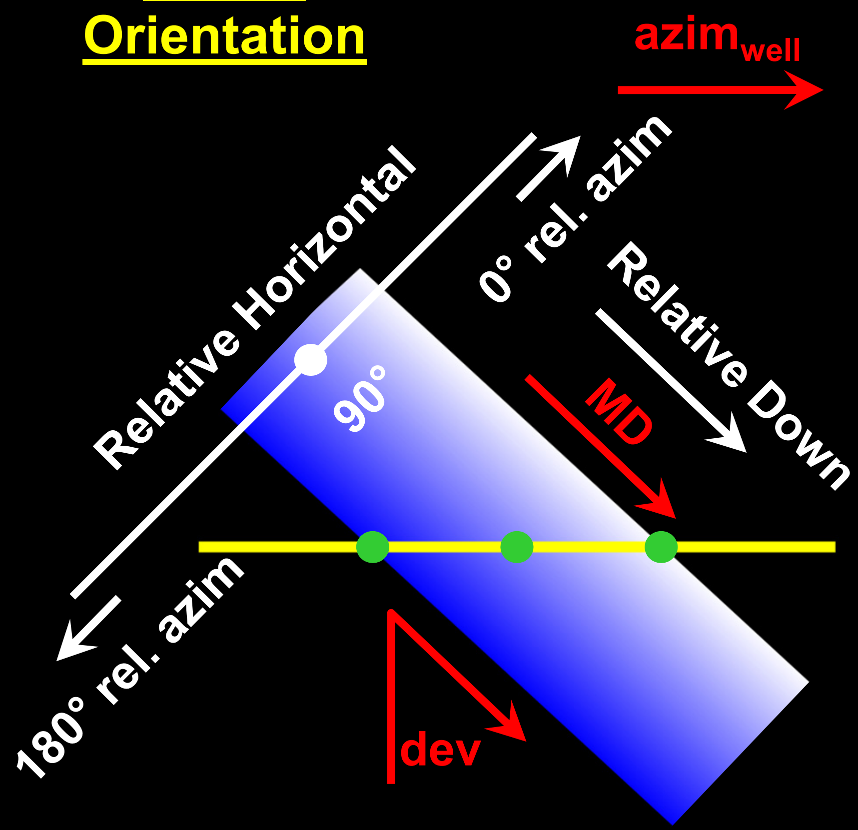


(Kurkoski and Hassan, 2007, International Patent WO 2007/011719 A1)

Relative Dip

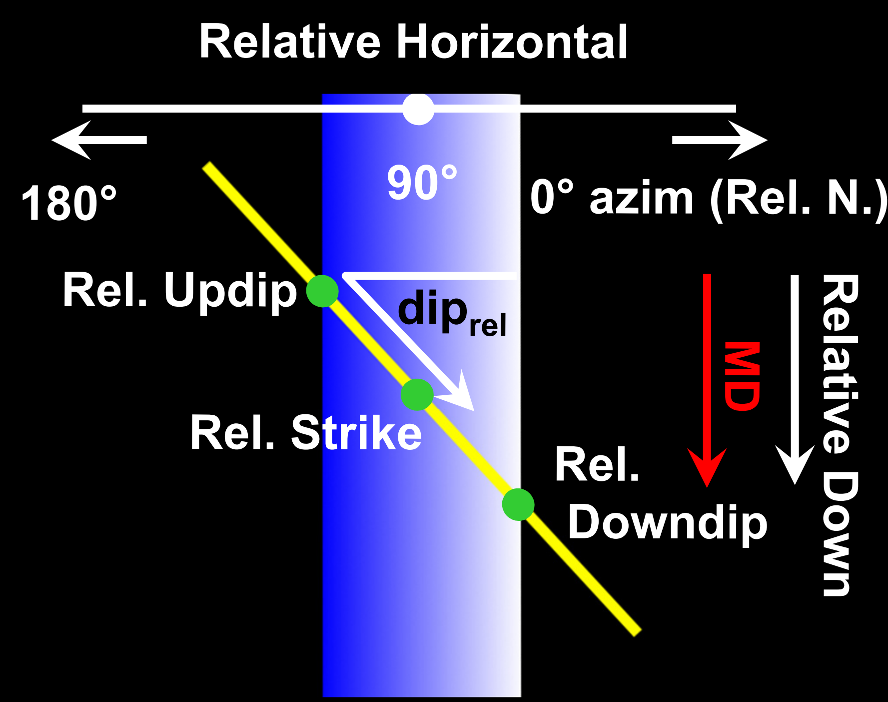
Coordinate System Relative to the Wellbore

Actual Orientation



- Note that the actual orientation of the intersecting plane is horizontal.

Relative Coordinate System



- Relative to the wellbore, however, the intersecting plane is dipping 45° in a Relative North (0° azimuth) direction.

Relative Dip
Wellbore Reference Frame

- Measured Depth (MD) logs are by default presented in the wellbore reference frame.
- An MD log is printed in a vertical profile with MD increasing downward, regardless of the true wellbore orientation.
- Image logs in particular provide insight into relative dip relations between the wellbore and geological planes.

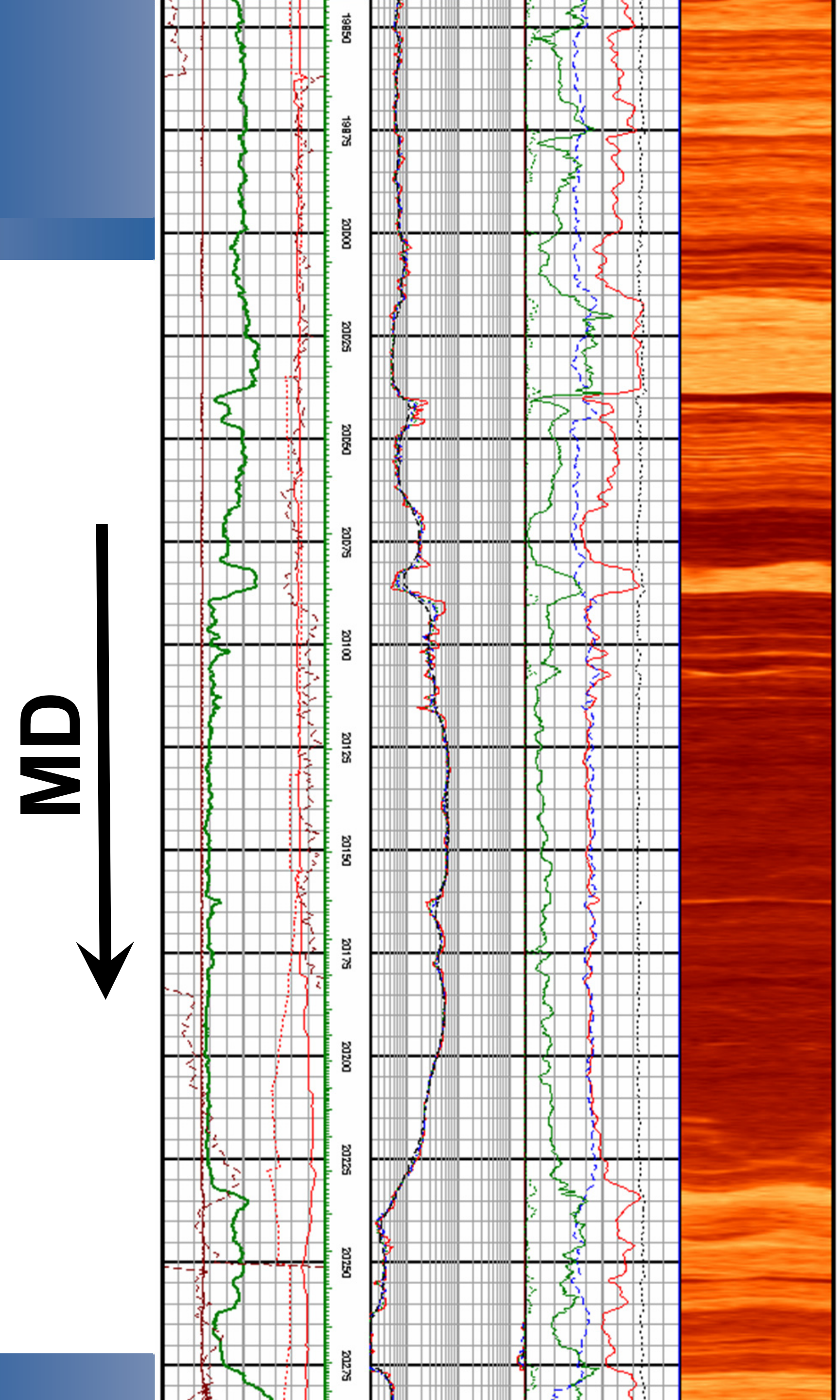
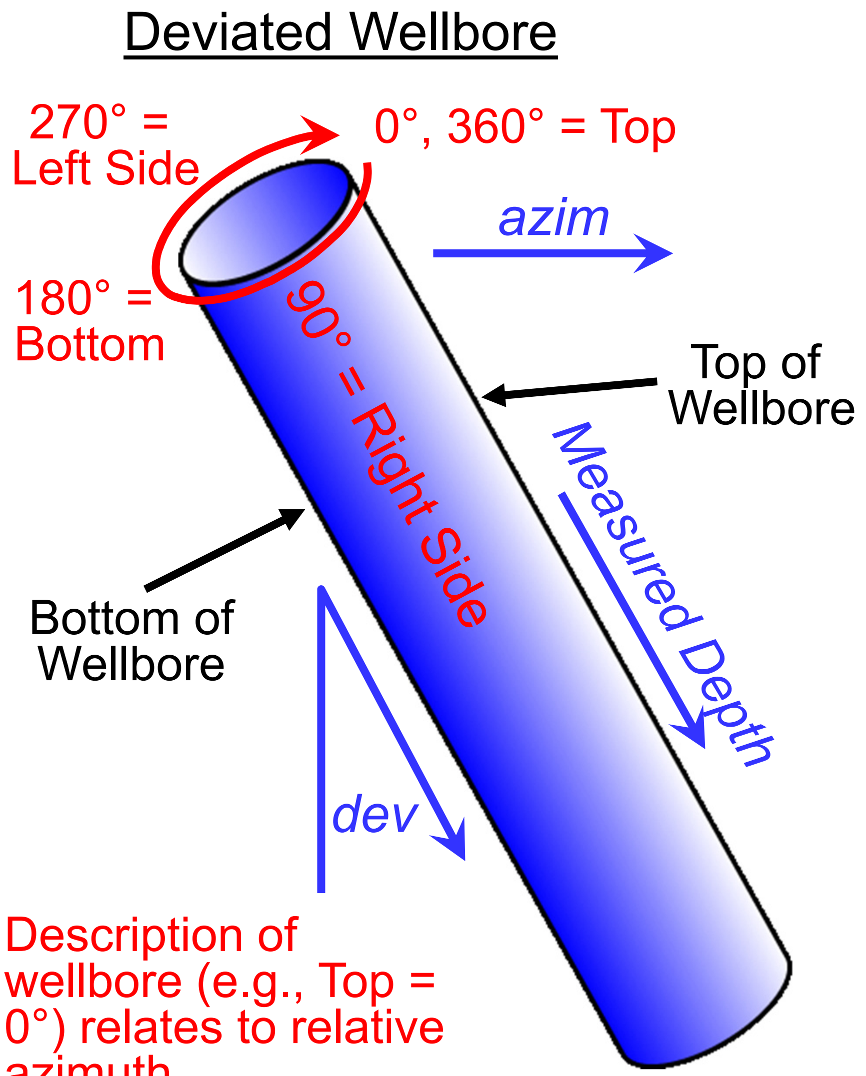


Image Log Format



Description of wellbore (e.g., Top = 0°) relates to relative azimuth.

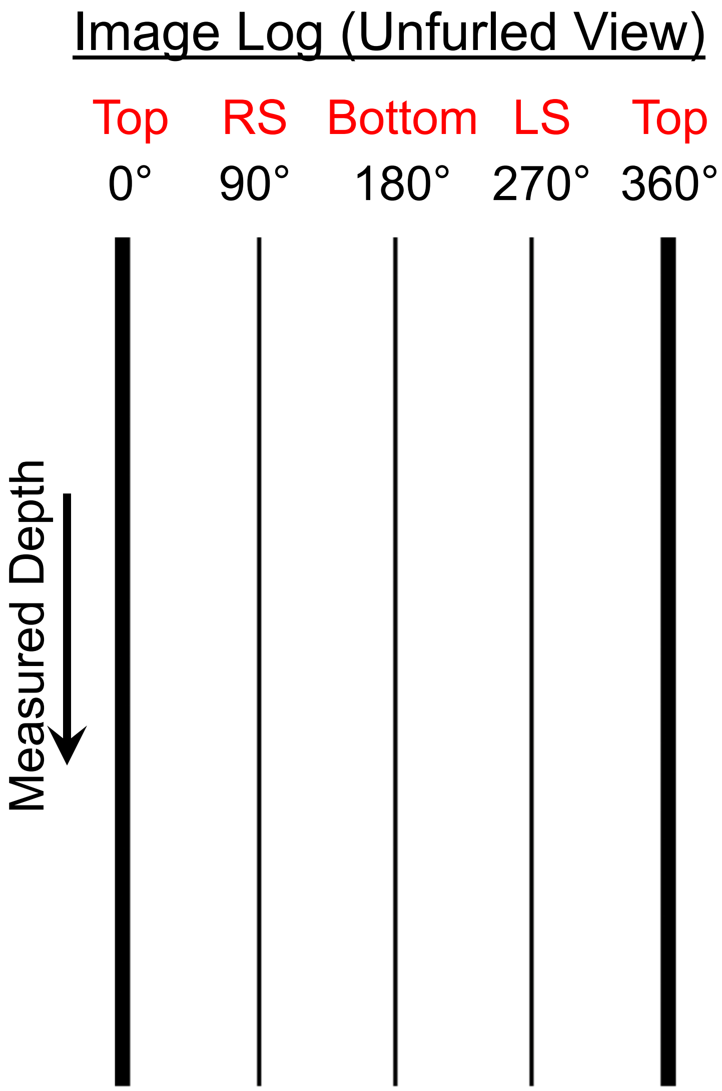
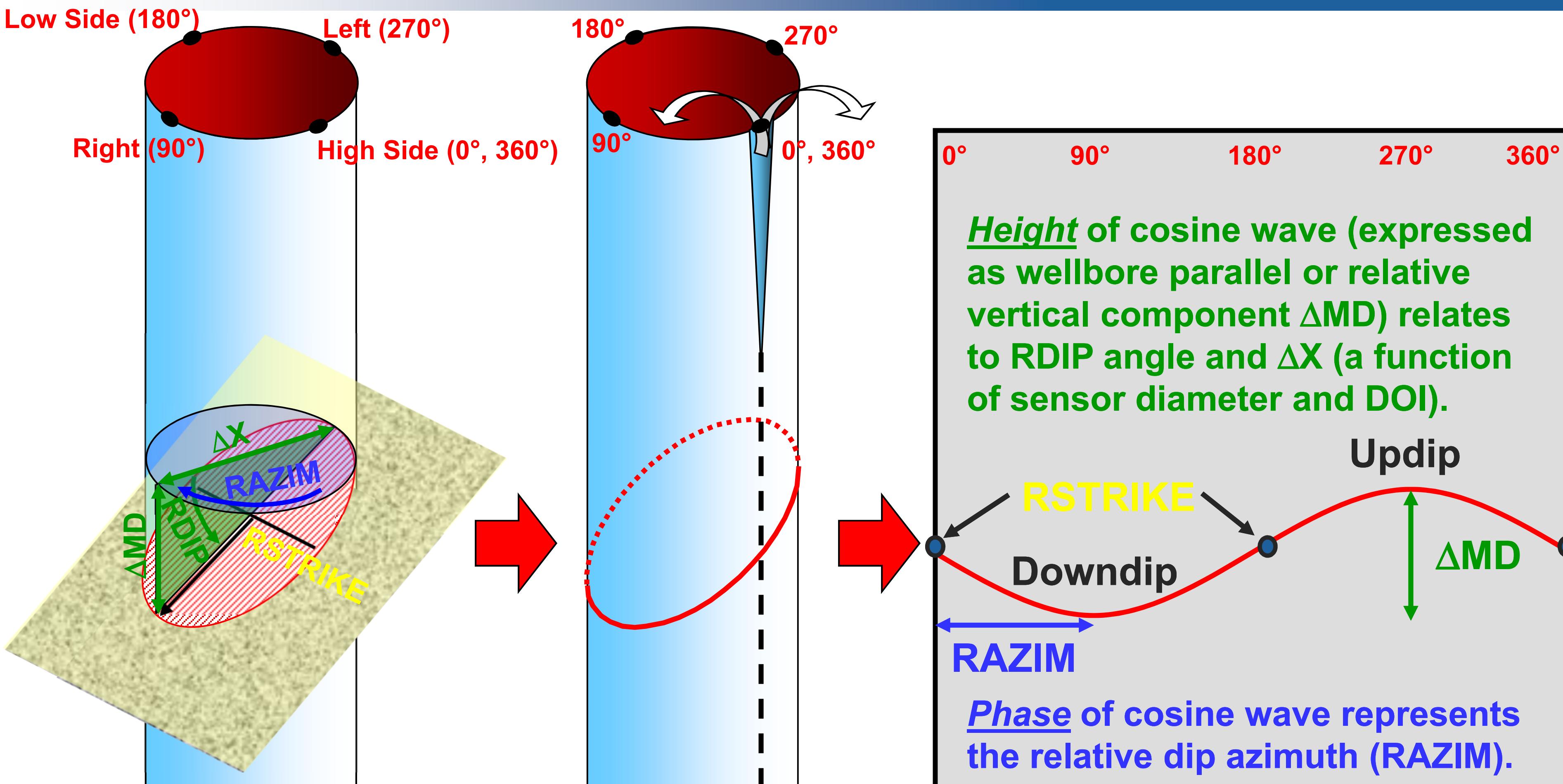


Image Log Format



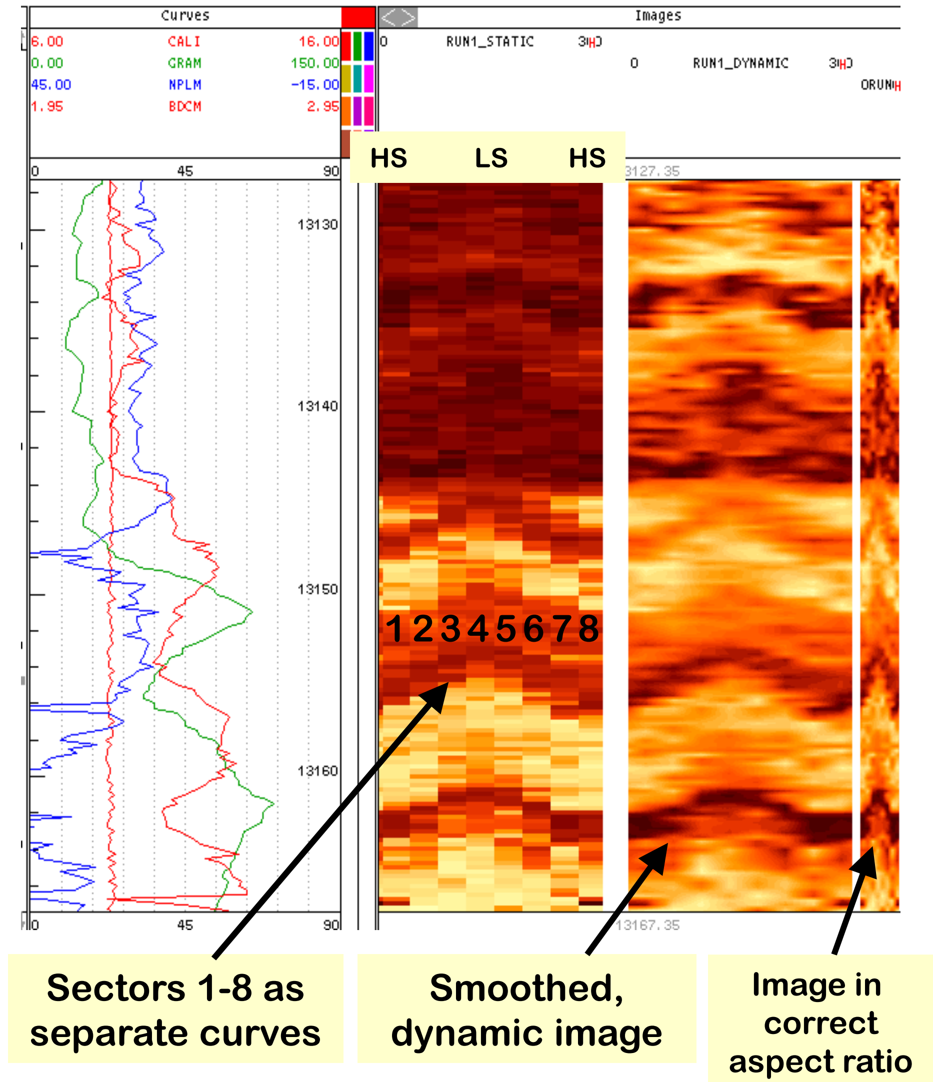
Inclined plane intersects tubular (near cylindrical) borehole, yielding an ellipse inclined to the well.

Image tube/cylinder is cut at the high-side position and unrolled.

Ellipse transforms to a cosine wave, whose amplitude and phase directly relates to relative dip angle and azimuth.

Image Log Format

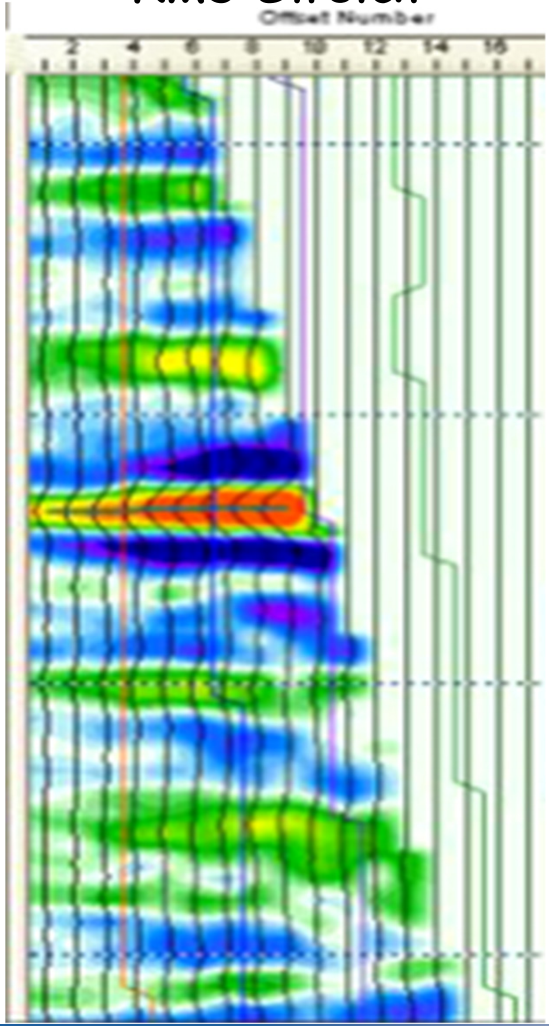
- An individual log curve is generated for each sector.
    - *Note color variations in each sector in left-hand image, each representing an individual log curve (density in this example) for each sector.*
- Sectors are then flattened (beginning High Side, and proceeding clockwise around borehole) to form the "raw" image.
- Horizontal and Vertical interpolations are applied as smoothing algorithms.
- Additional image enhancement (e.g., dynamic normalization) can also be applied.



Stacking Smearing of Amplitudes
Amplitudes may be Compromised during Stacking

- Although stacking generally improves the signal to noise ratio, the stacked section does not necessarily represent the real normal incidence reflectivity.
- For data with AVO effects this can cause problems during well-tie and wavelet estimation.
- NMO stretching and non-hyperbolic moveout can likewise cause “smearing” of the stacked trace amplitudes.
- And where reflectivity variations are averaged out, the inverted P-impedance diverges from the true P-impedance.

AVO Effect and NMO Stretch



Non-Hyperbolic Moveout

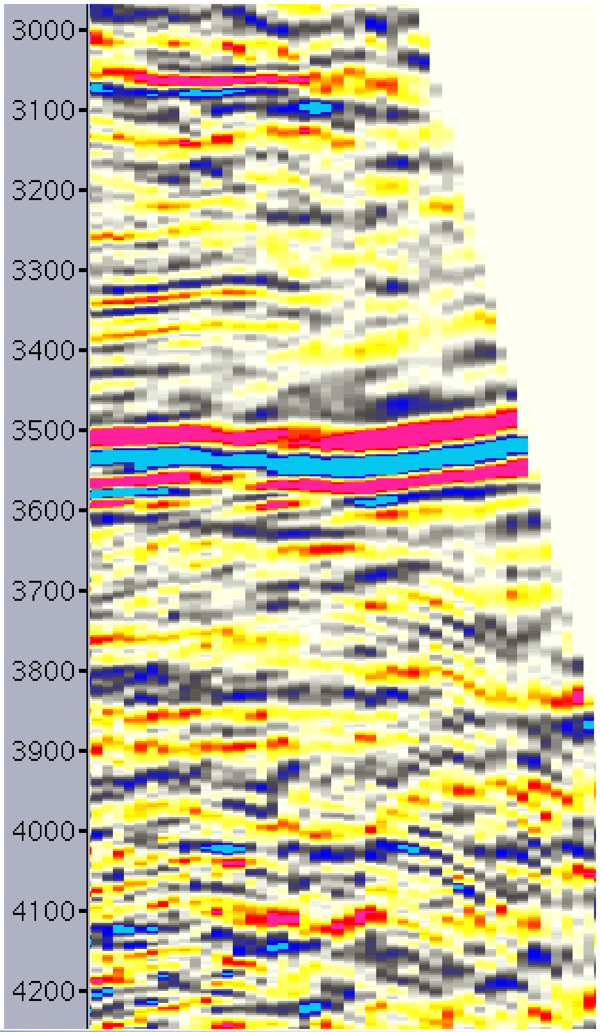
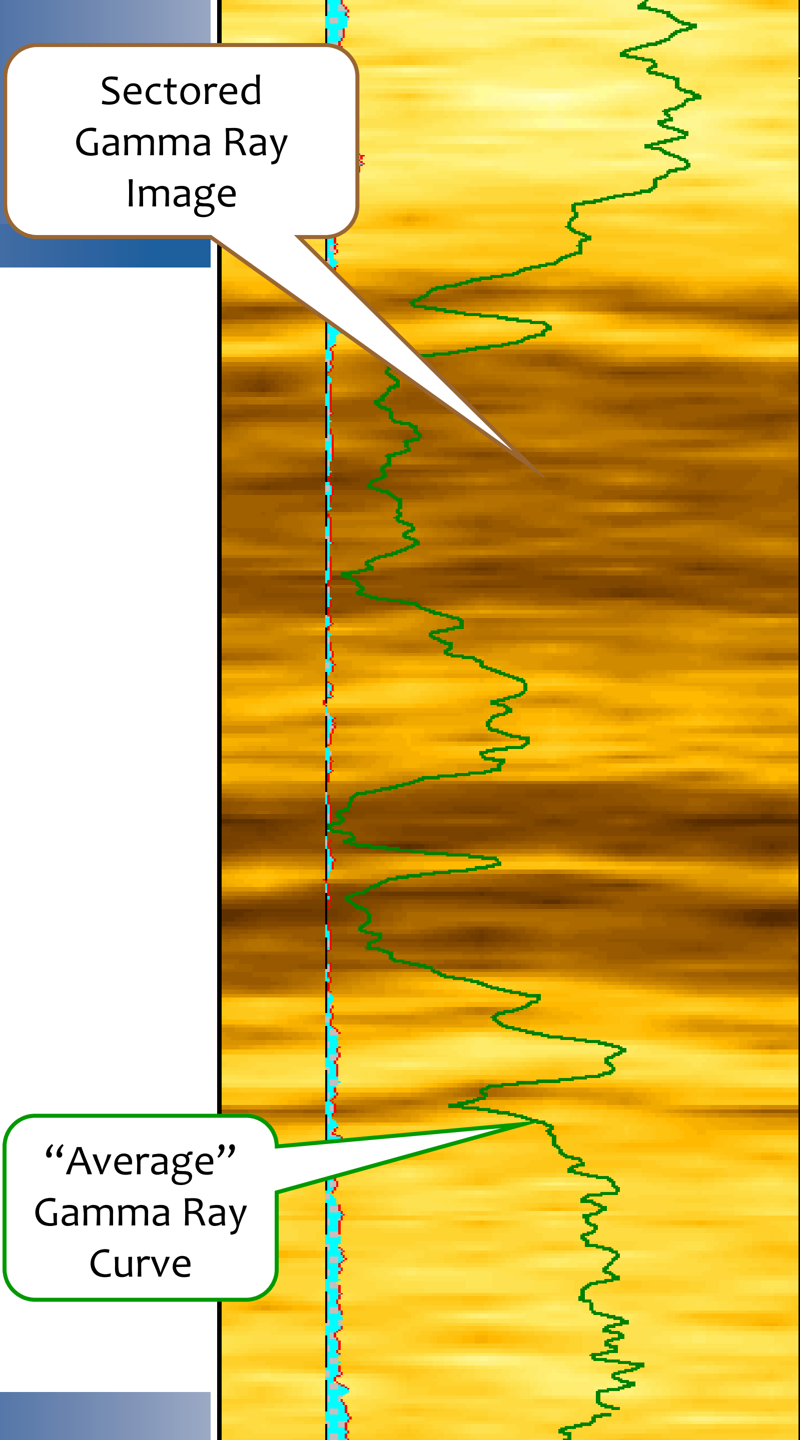
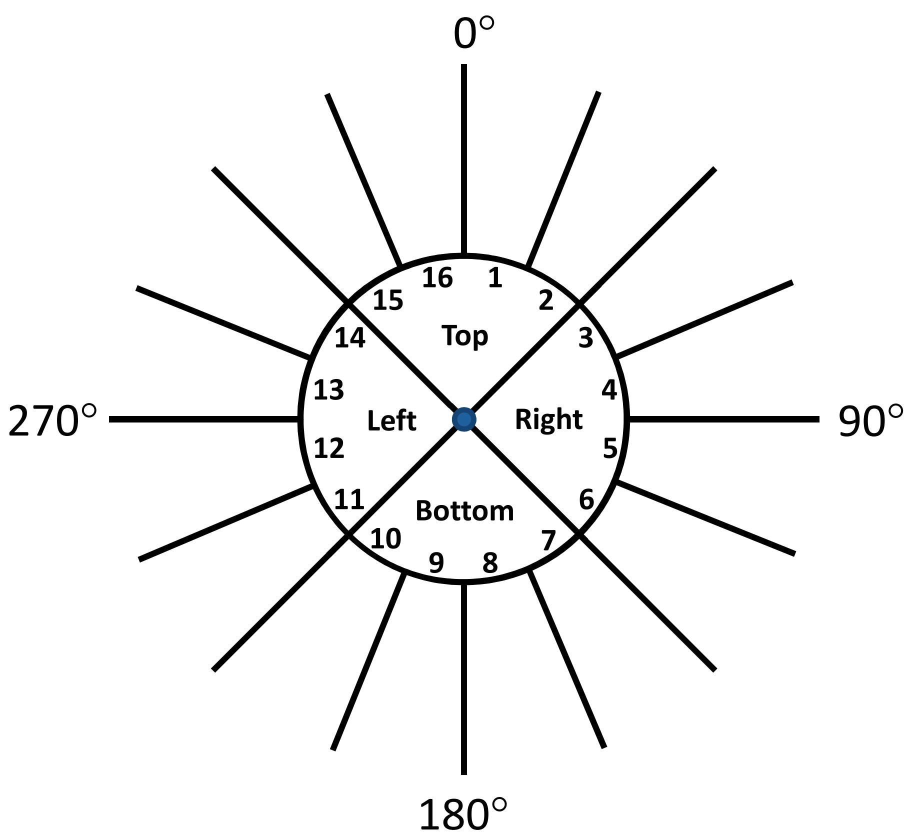


Image Log Format

- Individual sector curves are "averaged" to yield an overall response curve.
  - *This averaged curve is that which is presented in the typical "wiggly-line" display on a log.*
  - *The average curve can be used to confirm general color scaling of the image log (i.e., do bright/warm tones represent high values and dark/cold to low values, or is scale reversed?)*



Standard Sectoring Approach
'Top Start' → Start at 0 deg and Count Clockwise

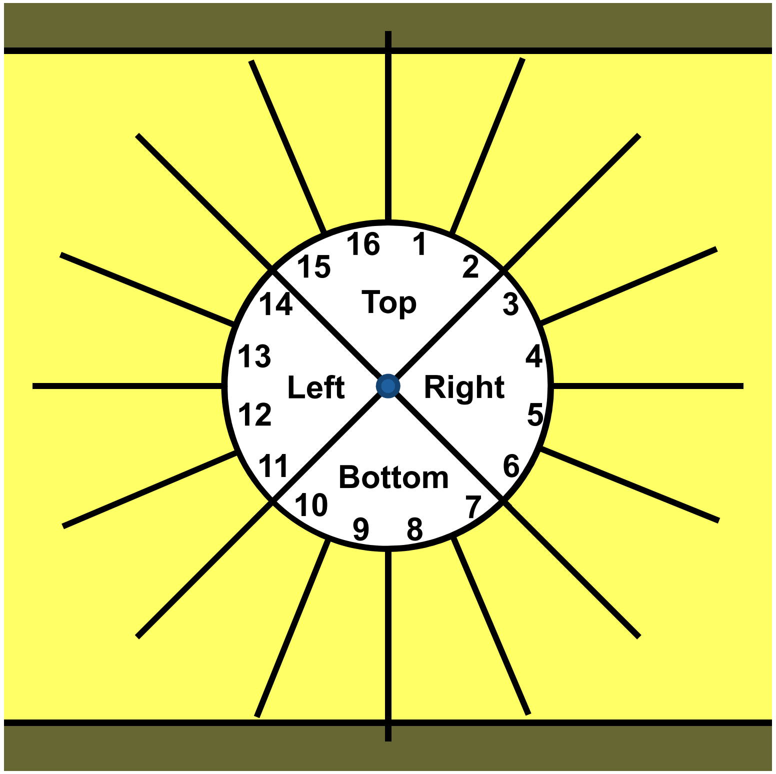


- In the standard sectoring system, the 1st sector starts at 0° (top side of borehole if deviated; north if vertical) and extends clockwise.
- Shown at left is a 16-sector example: sector 1 = 0–22.5°, sector 2, 22.5–45°, etc.
- Often sectors are averaged into quadrants for real-time transmission with limited bandwidth.

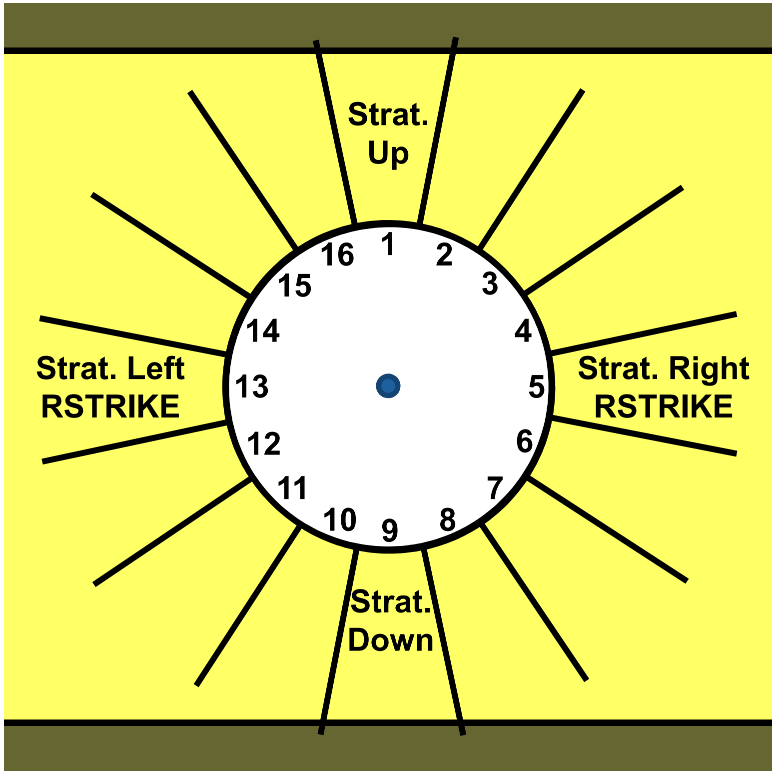
Geocentric Sectoring Approach
Orient Sectors According to Geology

HORIZONTAL BED EXAMPLE

Top-Start Sectoring System



Geocentric Sectoring System

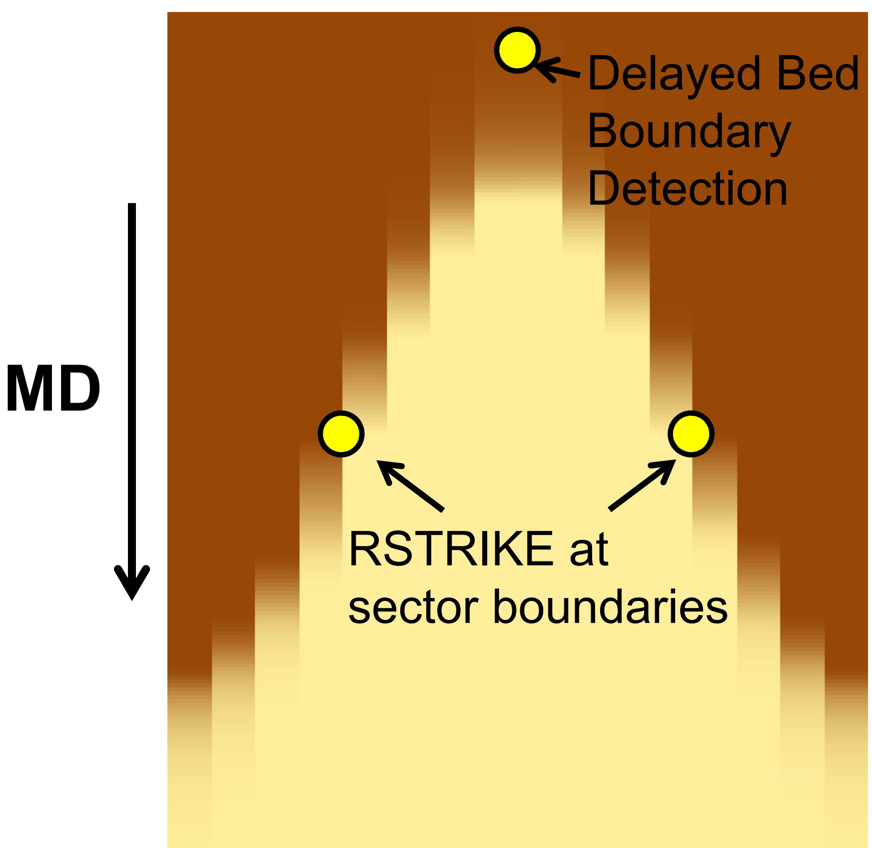


Geocentric Sectoring Approach

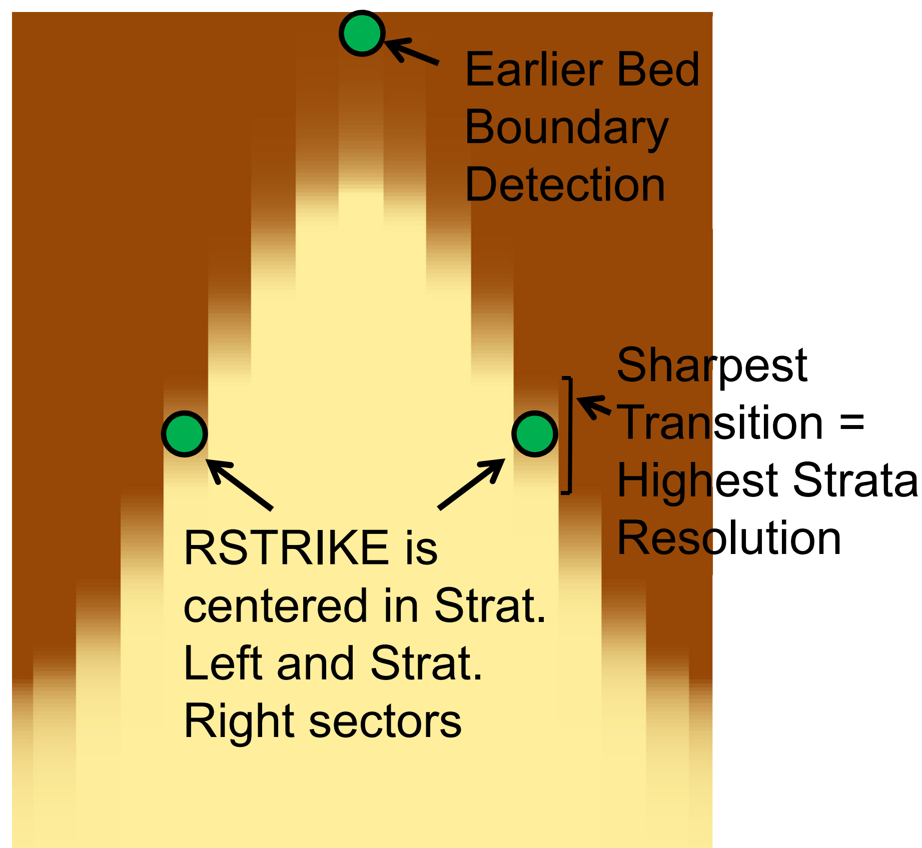
Orient Sectors According to Geology

HORIZONTAL BED EXAMPLE

Top-Start Sectoring System



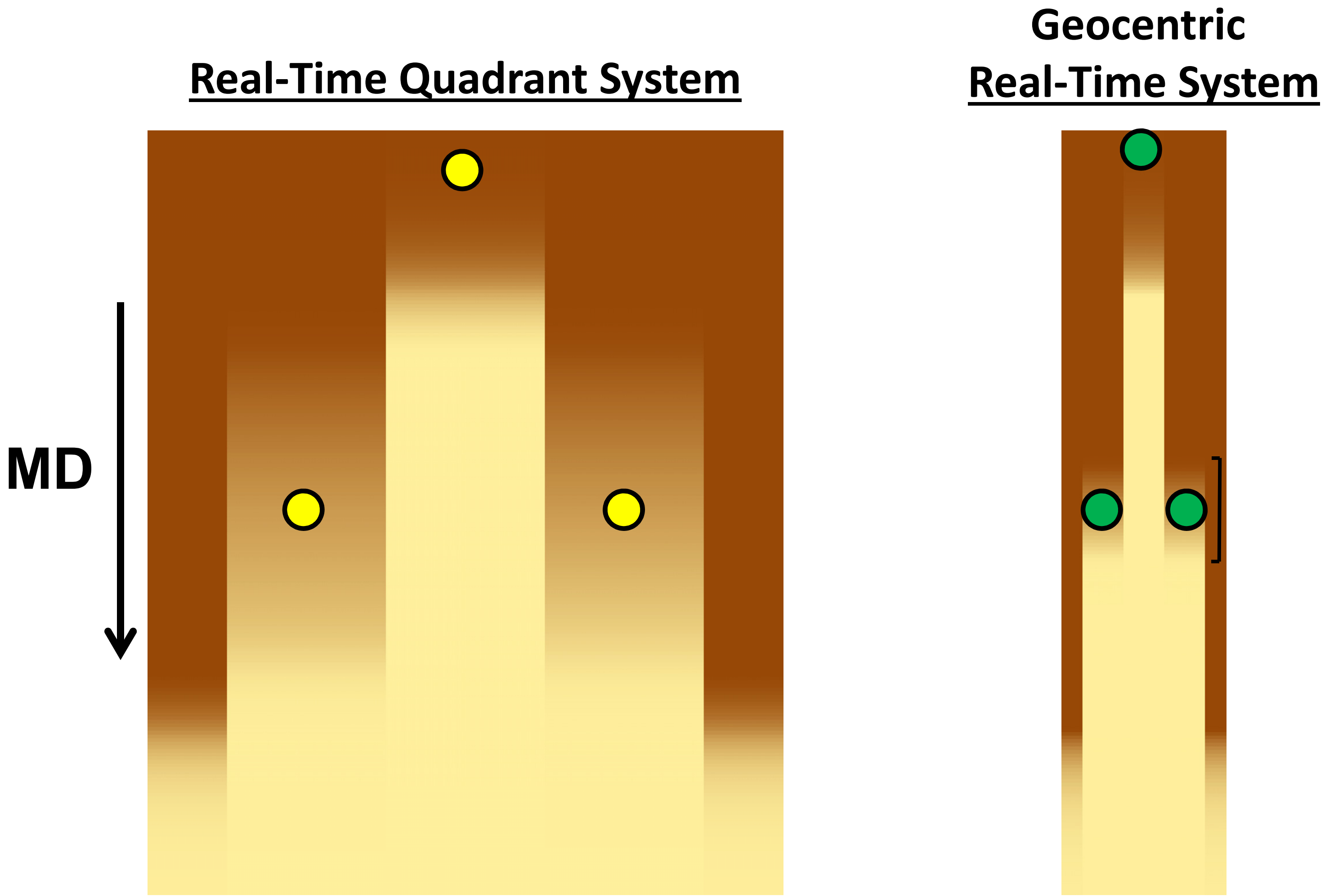
Geocentric Sectoring System



Geocentric Sectoring Approach

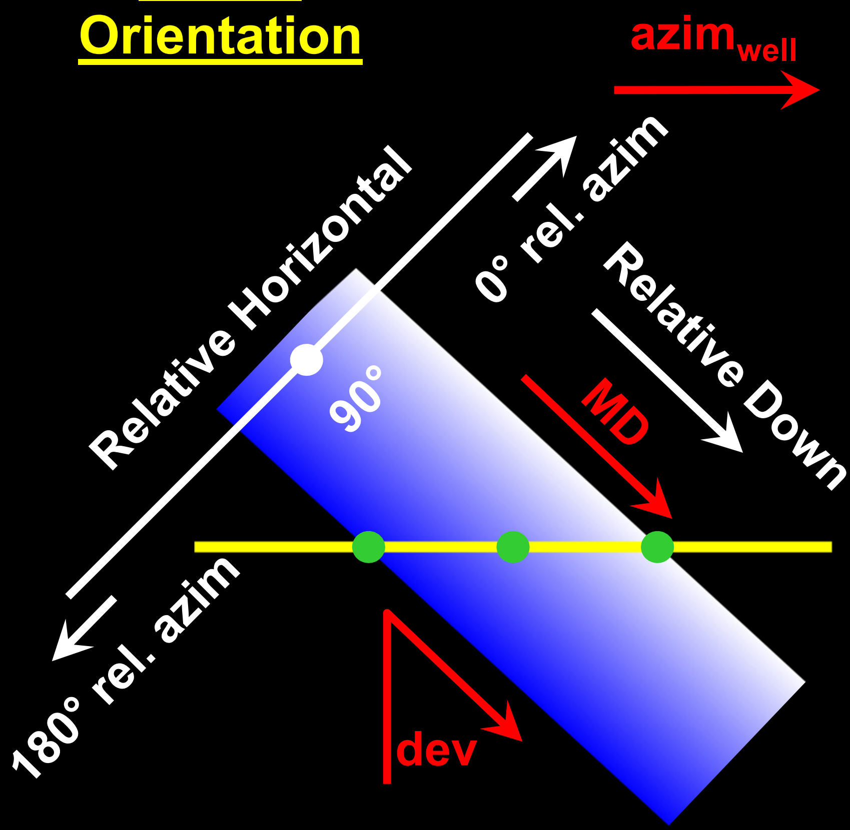
Orient Sectors According to Geology

HORIZONTAL BED EXAMPLE



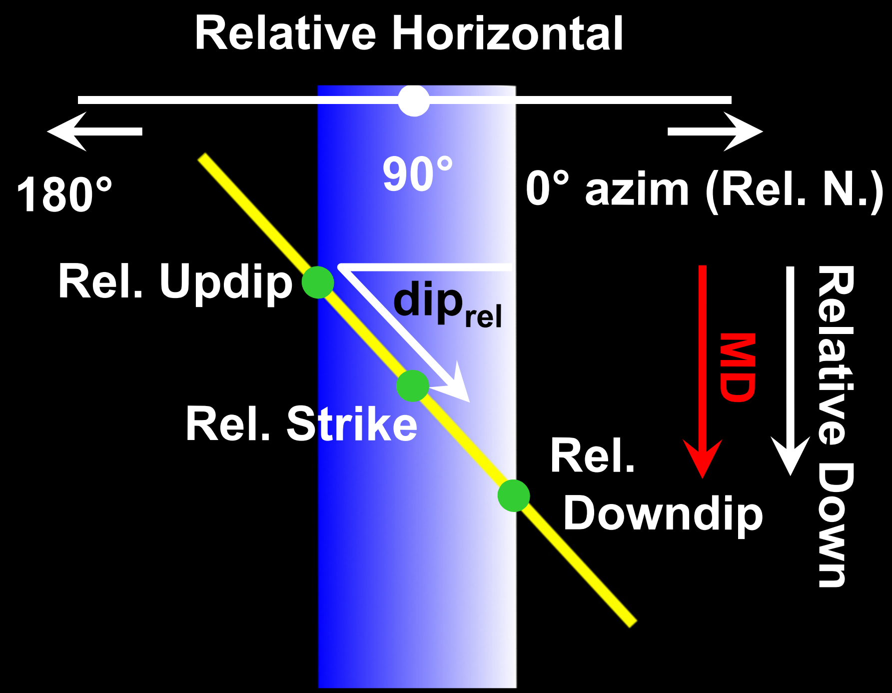
Relative Strike
Coordinate System Relative to the Wellbore

Actual Orientation



- Note that the actual orientation of the intersecting plane is horizontal.

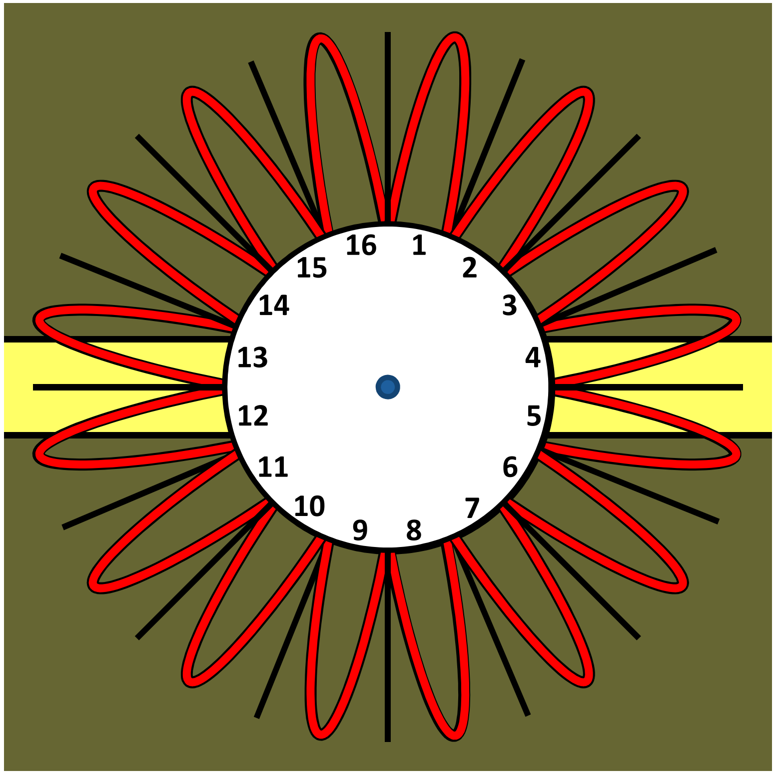
Relative Coordinate System



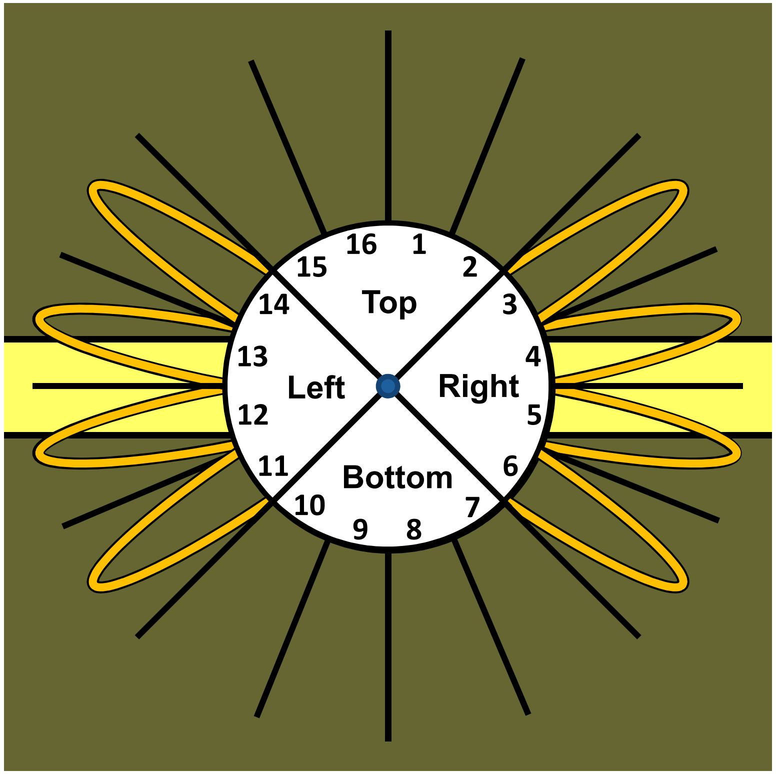
- Relative to the wellbore, however, the intersecting plane is dipping 45° in a Relative North (0° azimuth) direction.

RSTRIKE Extraction
Time-Average and Quadrant

<u>Time Average (All Sectors)</u>

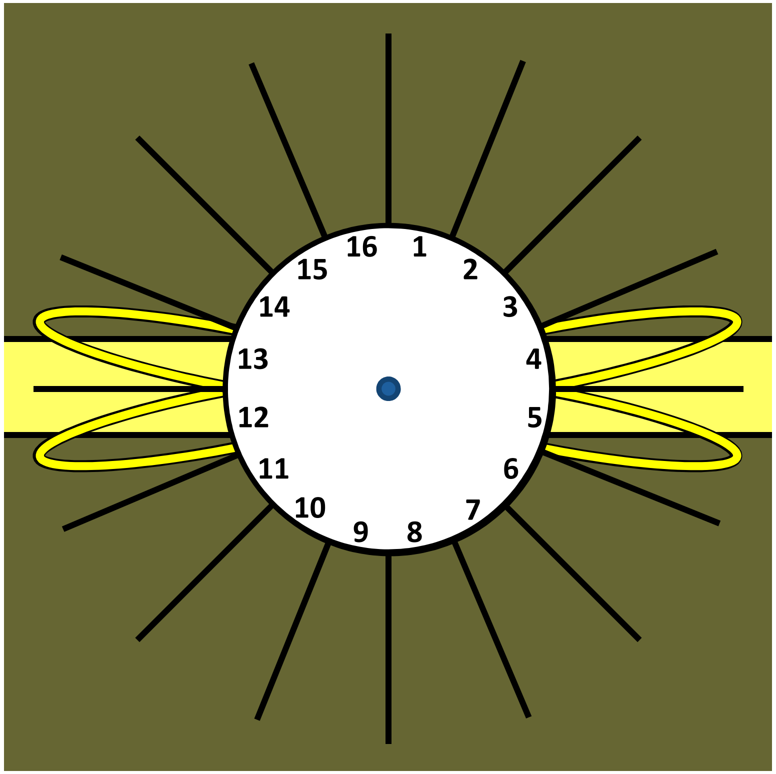


RSTRIKE Extraction from
<u>Typical Quadrant System</u>

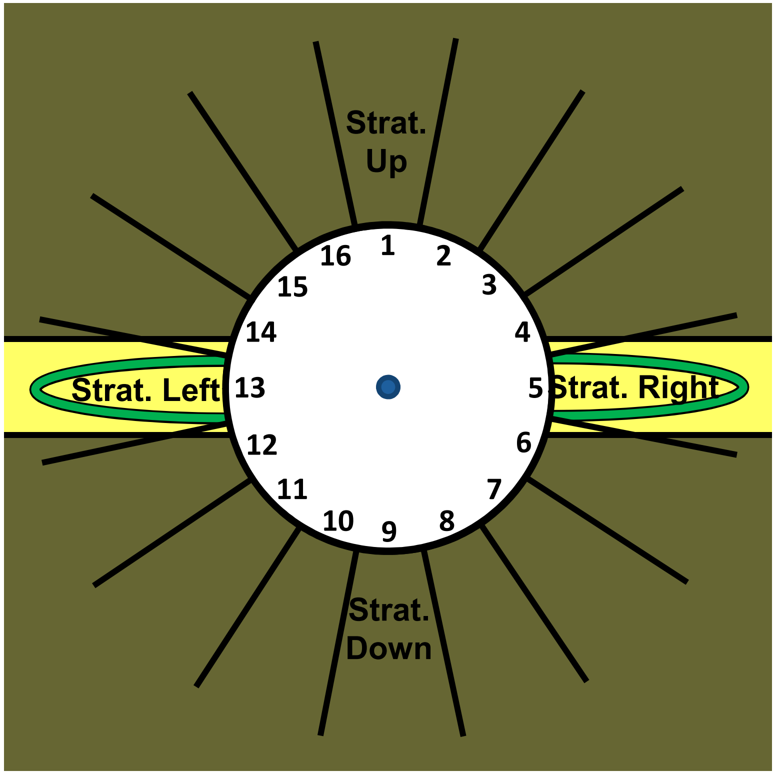


RSTRIKE Extraction
Octant versus Geocentric

RSTRIKE Extraction from <u>Typical Sectoring System</u>

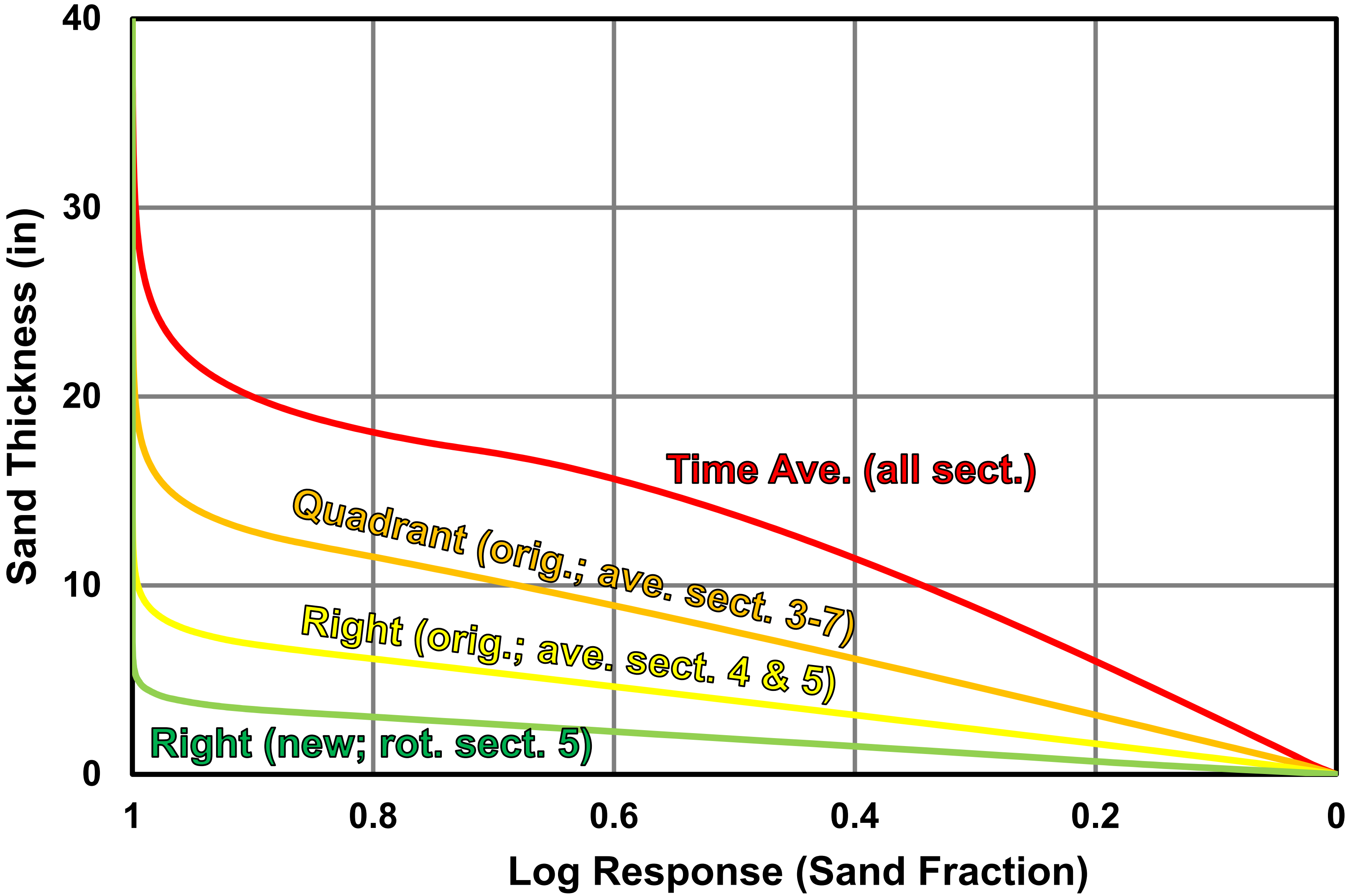


RSTRIKE Extraction from <u>Geocentric Sectoring System</u>

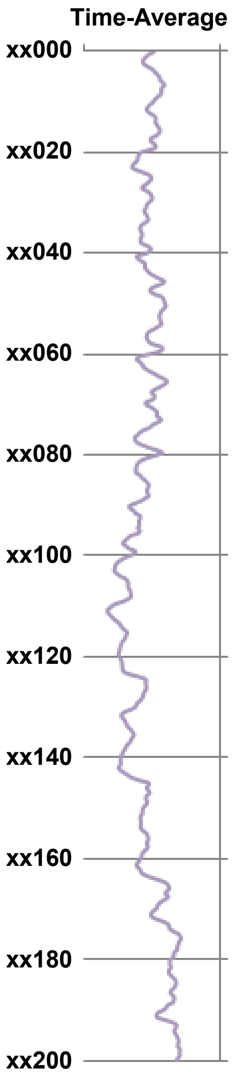


RSTRIKE Extraction

Resolution versus Sectoring Style

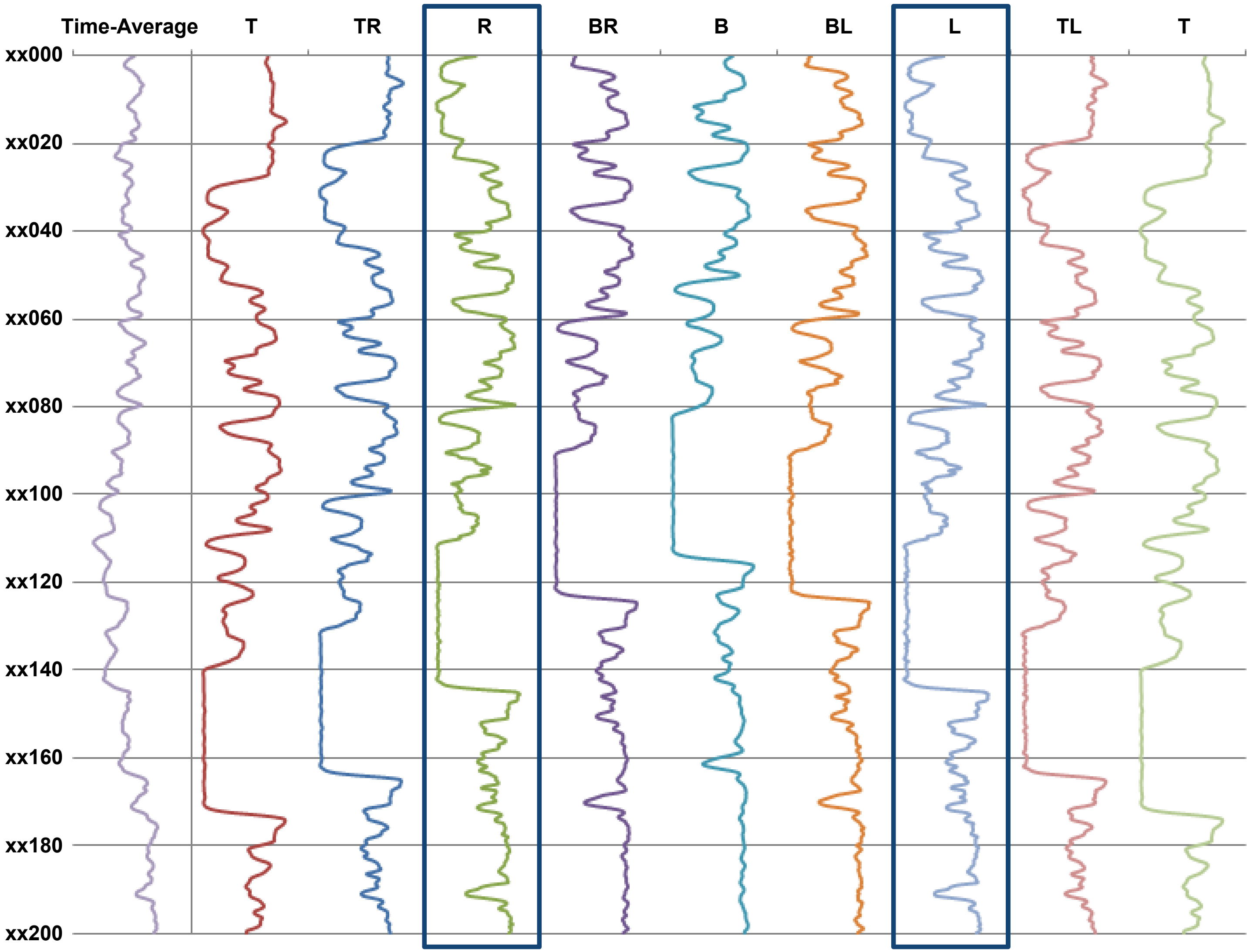


Time-Average Gather and Stack

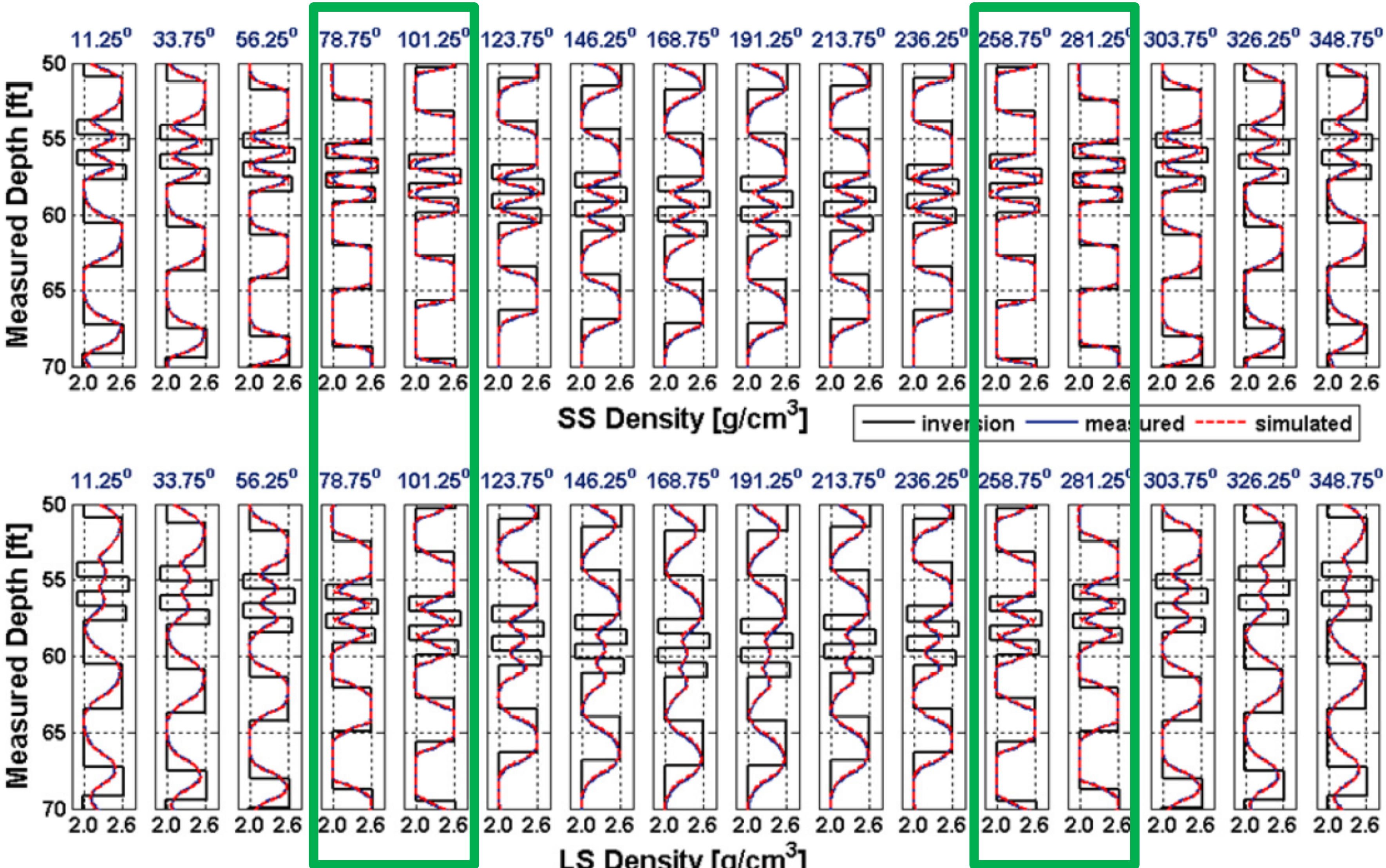


Sector Curves

RSTRIKE Sectors Highlighted



Sector Curves
RSTRIKE Sectors Highlighted



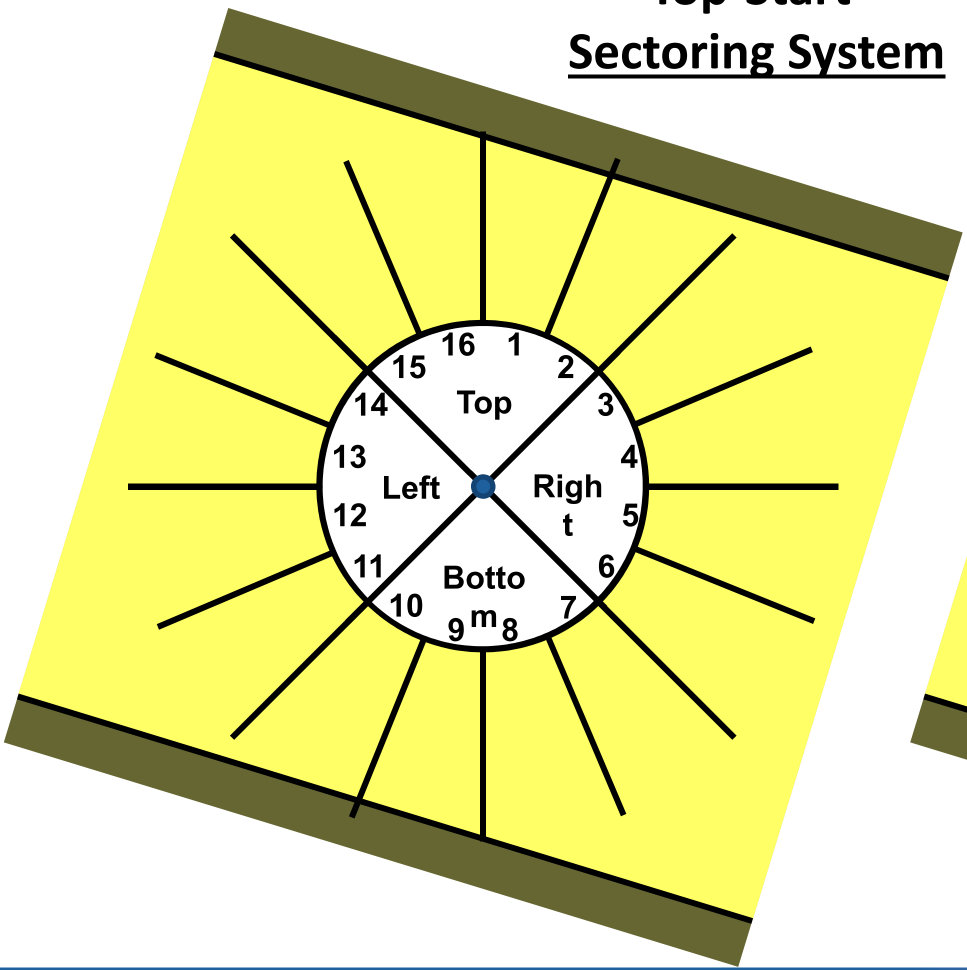
(Mendoza et al., 2009, SWPLA)

Geocentric Sectoring Approach

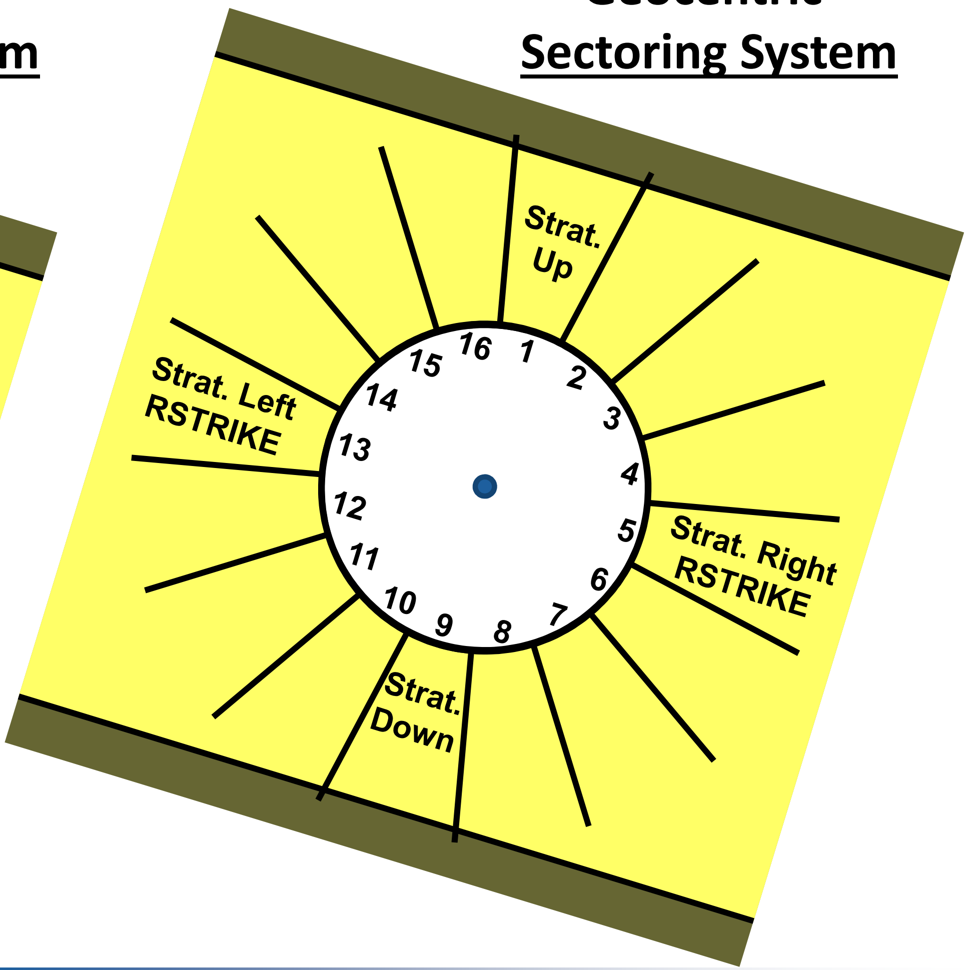
Orient Sectors According to Geology

DIPPING BED EXAMPLE

Top-Start
Sectoring System

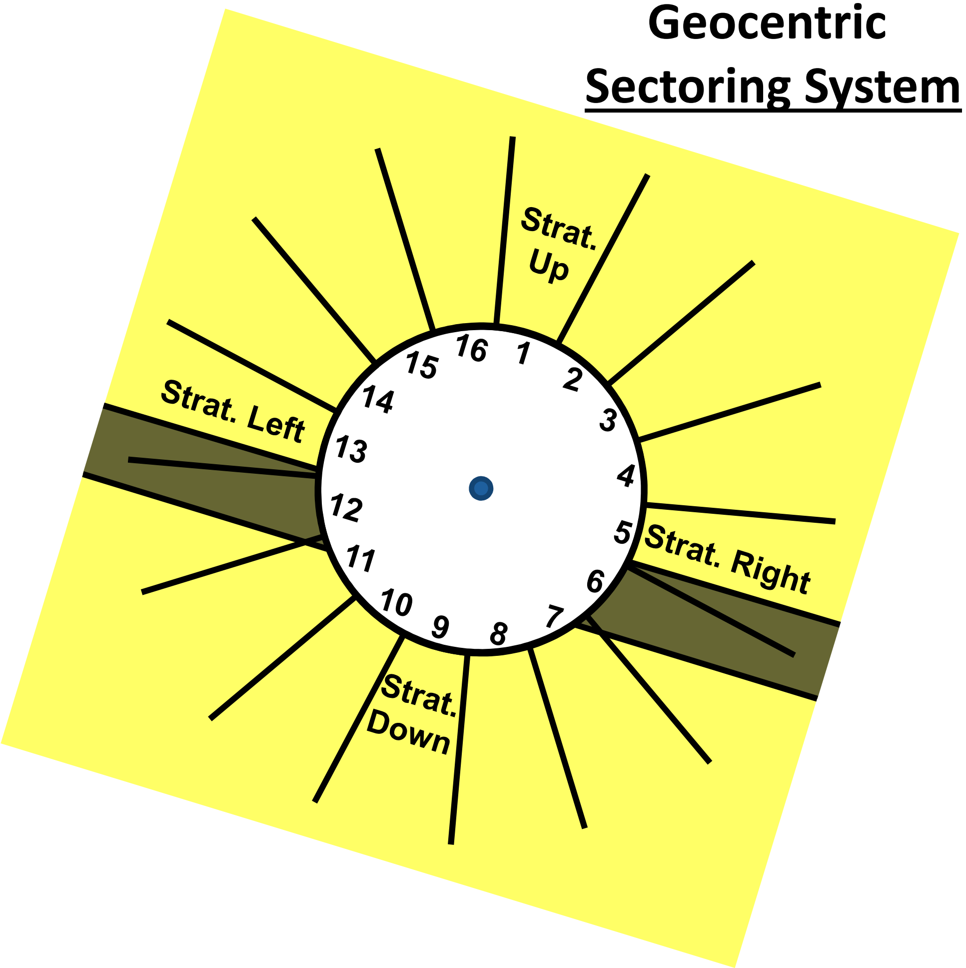


Geocentric
Sectoring System



Geocentric Sectoring
Adjusting to Geologic Changes

DIPPING BED EXAMPLE



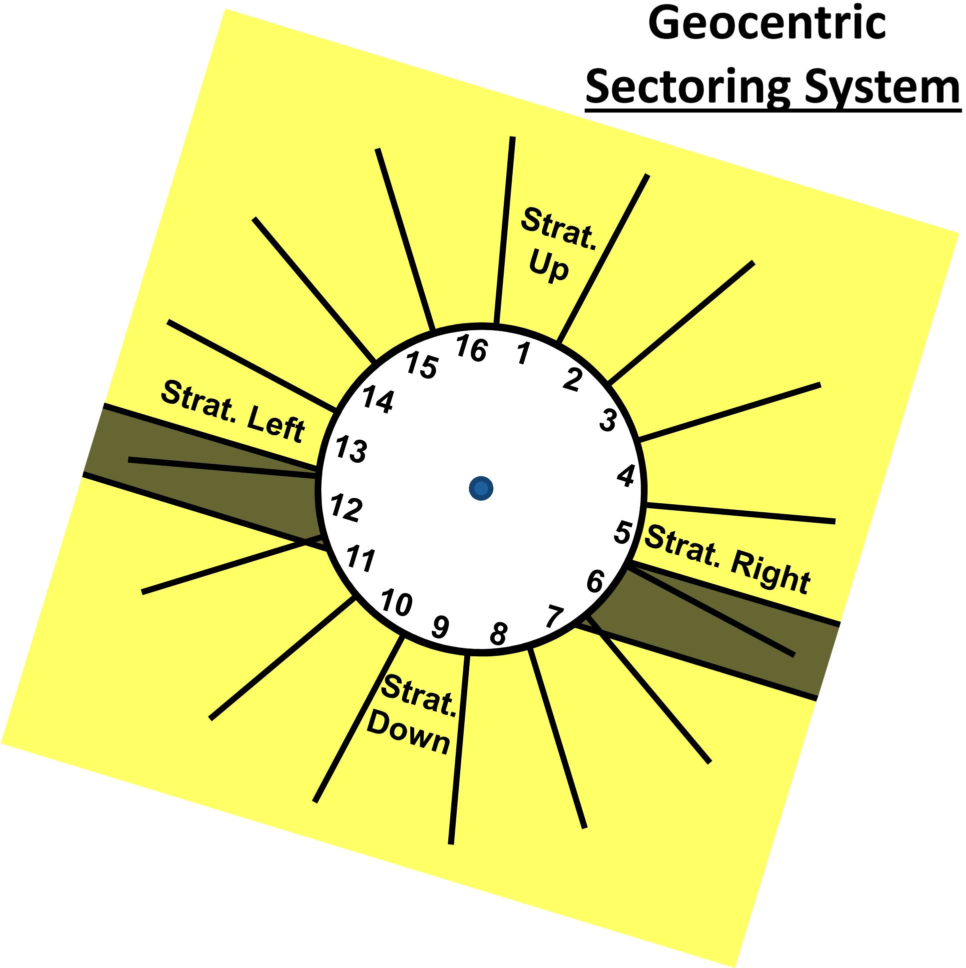
Geocentric Sectoring System	STRAT LEFT	STRAT RIGHT

Geocentric Sectoring
Adjusting to Geologic Changes

DIPPING BED EXAMPLE

Geocentric

Sectoring System



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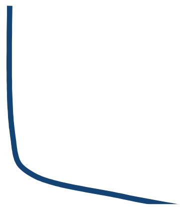

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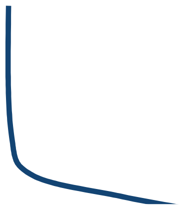
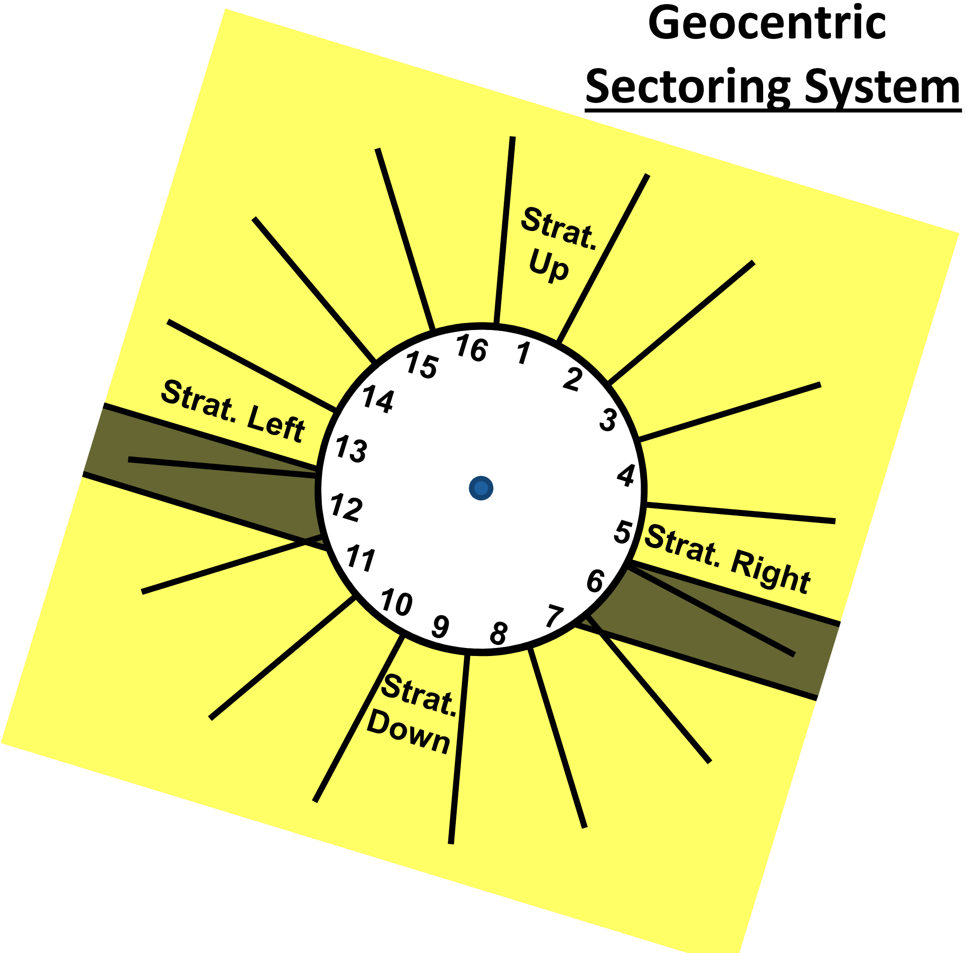


Geocentric Sectoring
Adjusting to Geologic Changes

DIPPING BED EXAMPLE

Geocentric
Sectoring System



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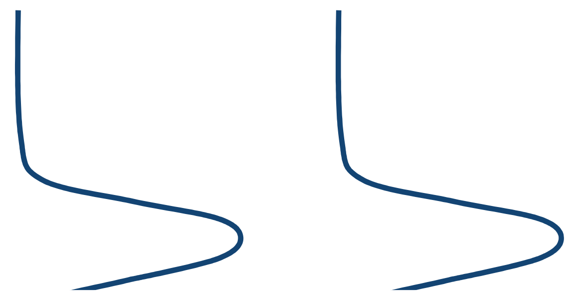
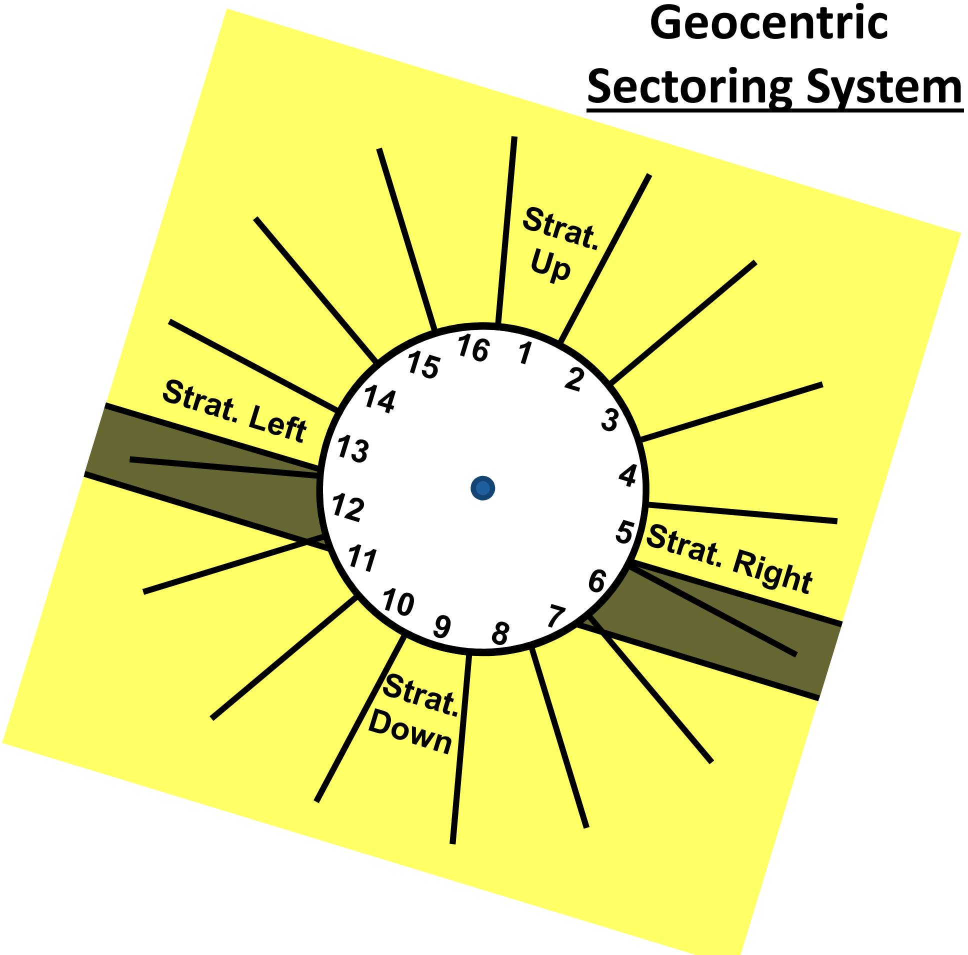


Geocentric Sectoring
Adjusting to Geologic Changes

DIPPING BED EXAMPLE



Geocentric
Sectoring System

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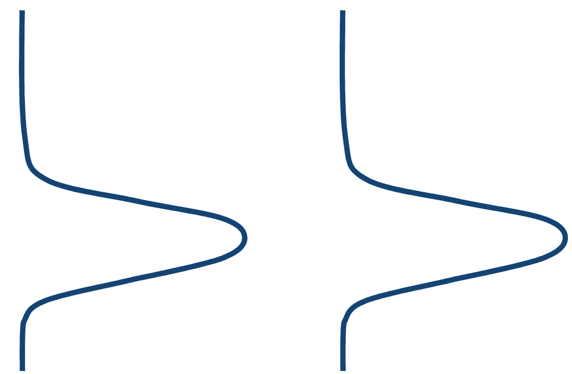

Geocentric Sectoring
Adjusting to Geologic Changes

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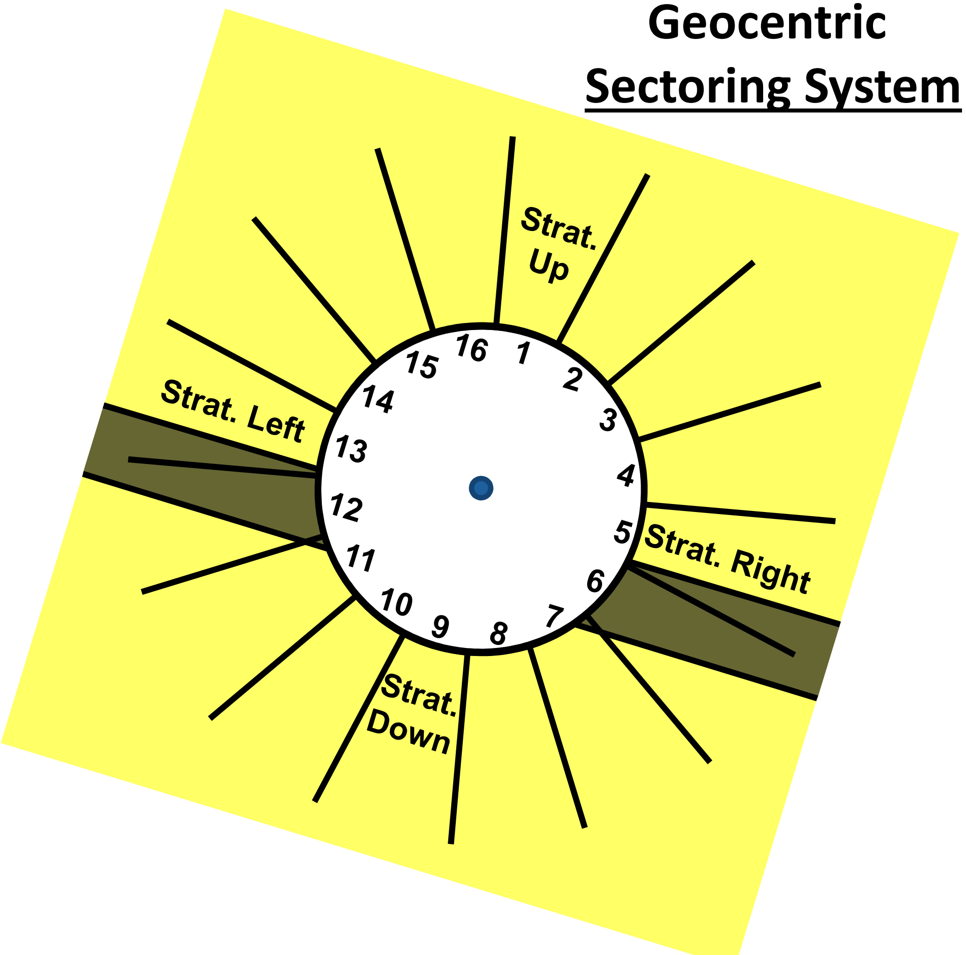
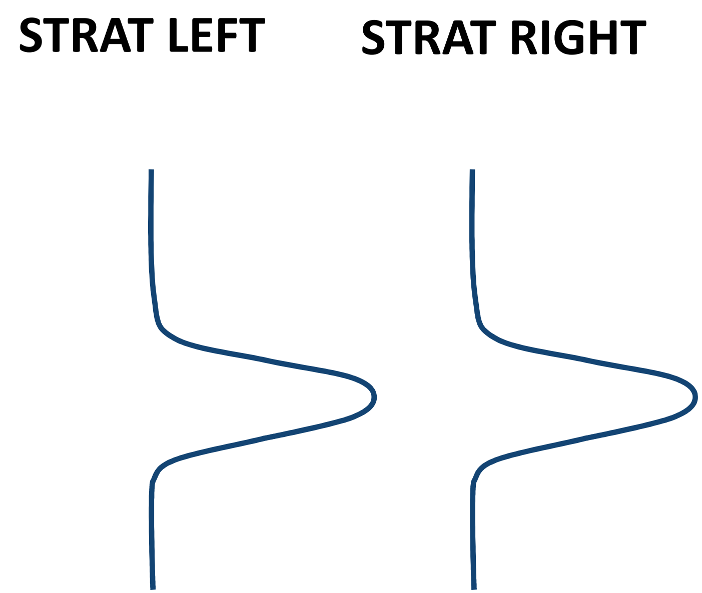
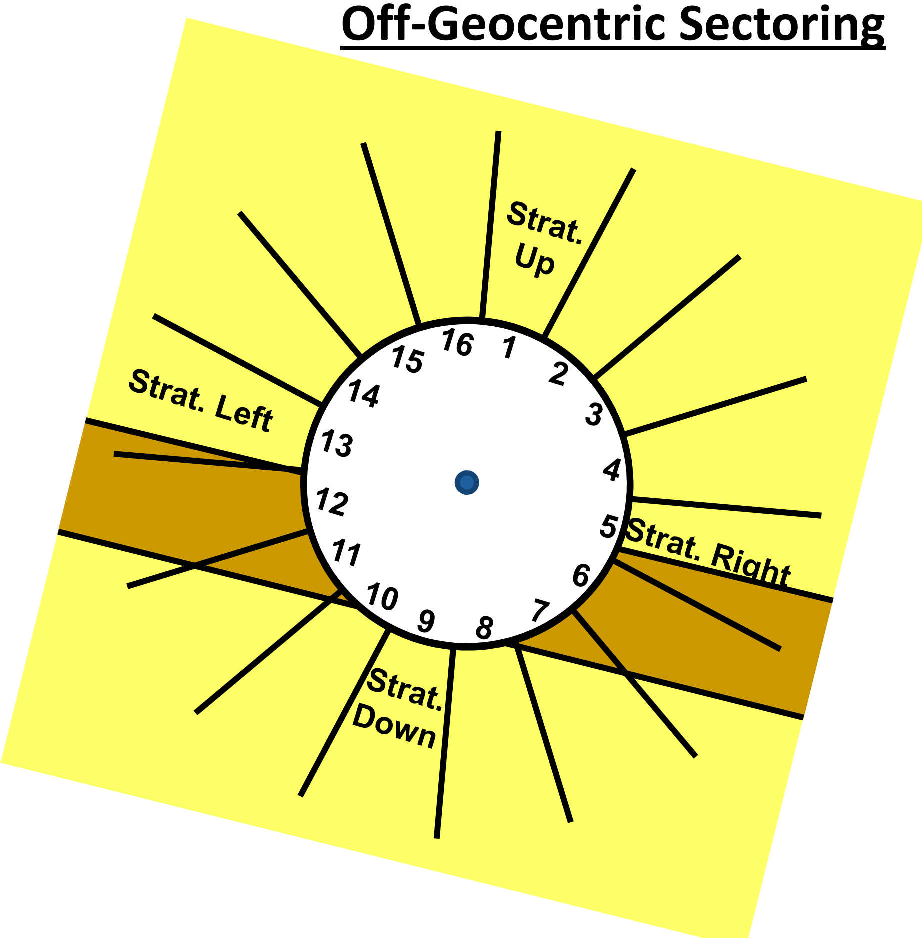




Geocentric Sectoring
Adjusting to Geologic Changes

DIPPING BED EXAMPLE

Formation Change causing
Off-Geocentric Sectoring



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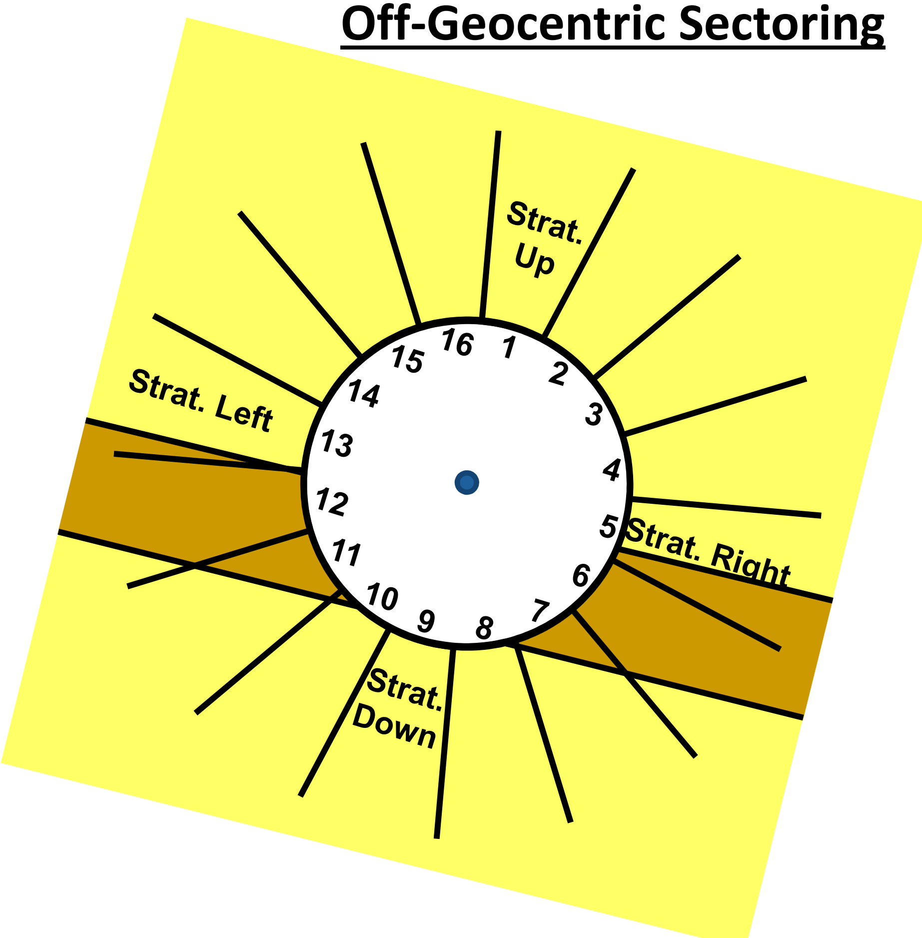
Geocentric Sectoring
Adjusting to Geologic Changes

DIPPING BED EXAMPLE

Formation Change causing
Off-Geocentric Sectoring



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Geocentric Sectoring
Adjusting to Geologic Changes

DIPPING BED EXAMPLE

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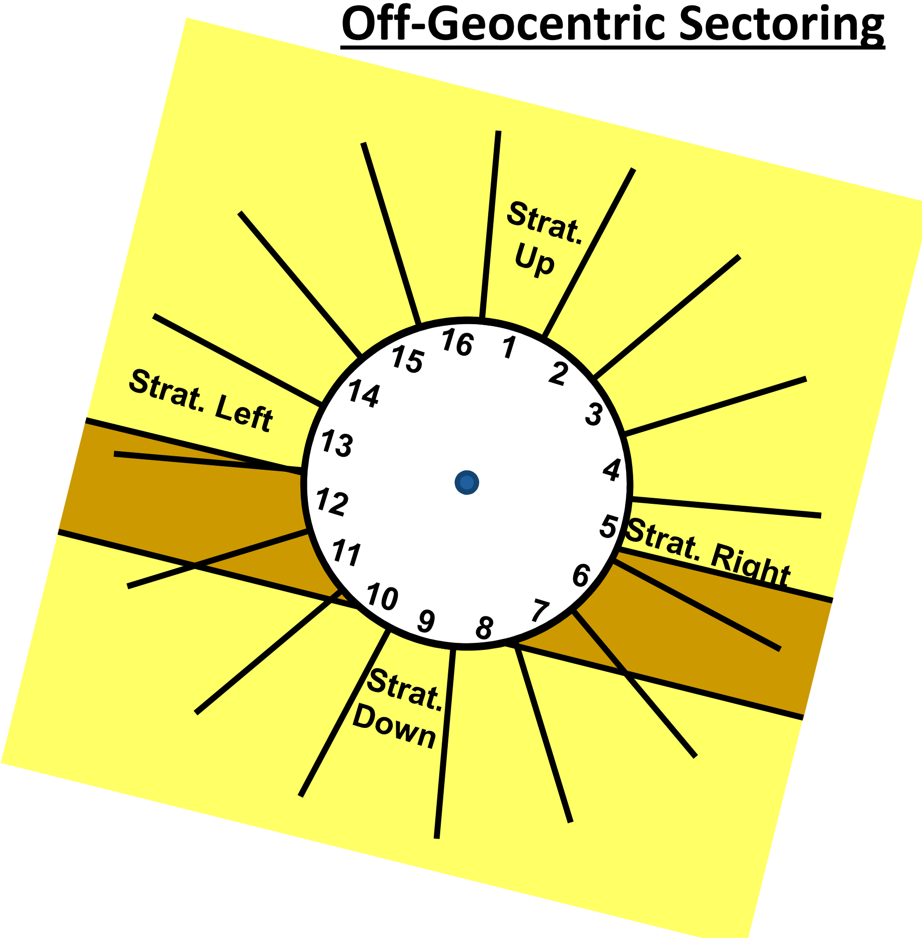

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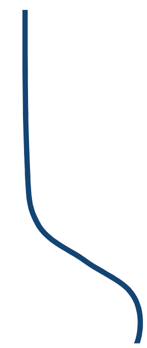

Geocentric Sectoring
Adjusting to Geologic Changes

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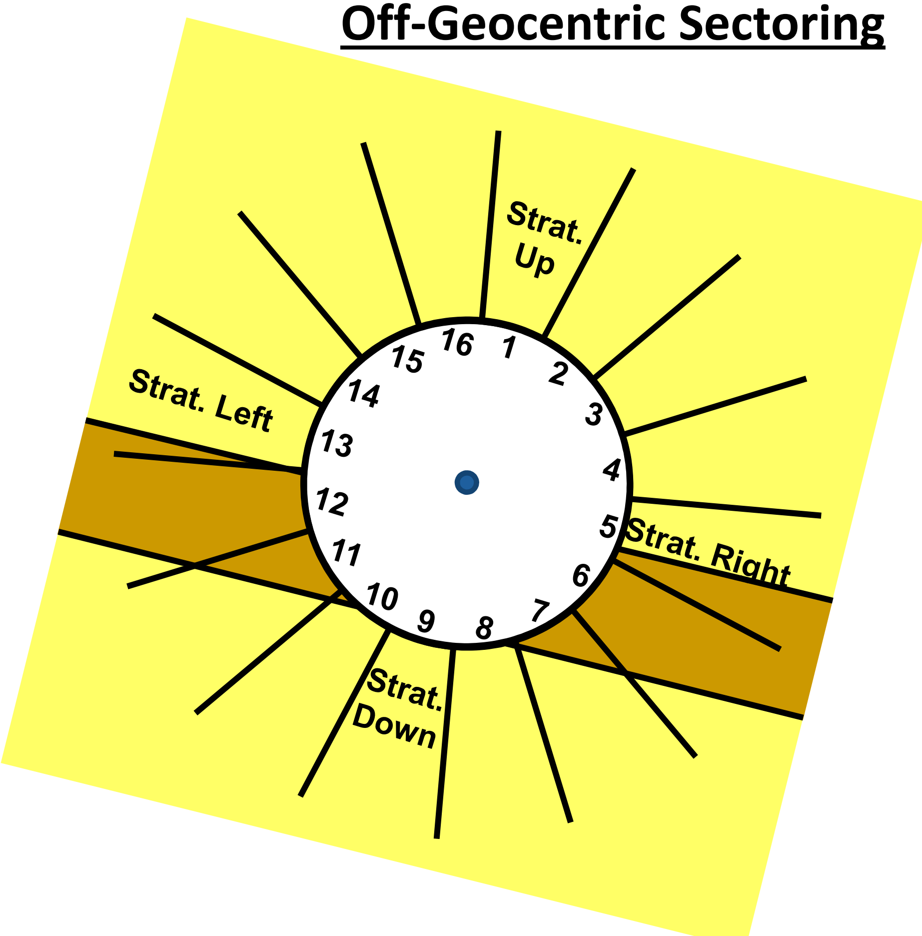
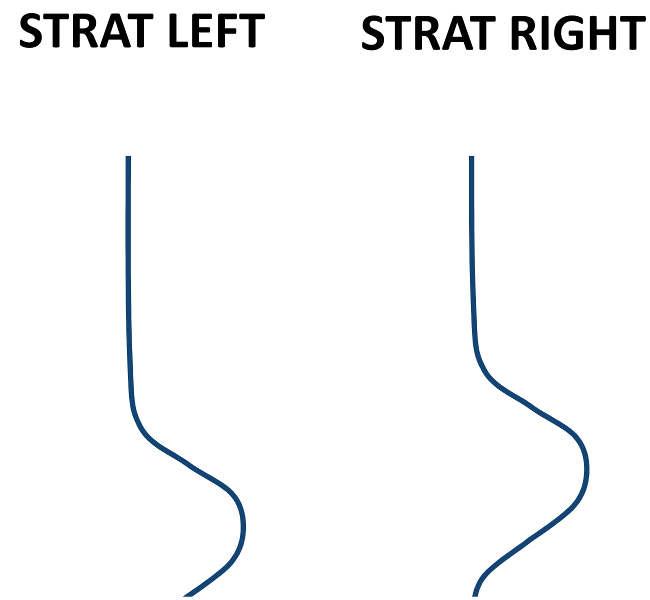
Formation Change causing
<u>Off-Geocentric Sectoring</u>





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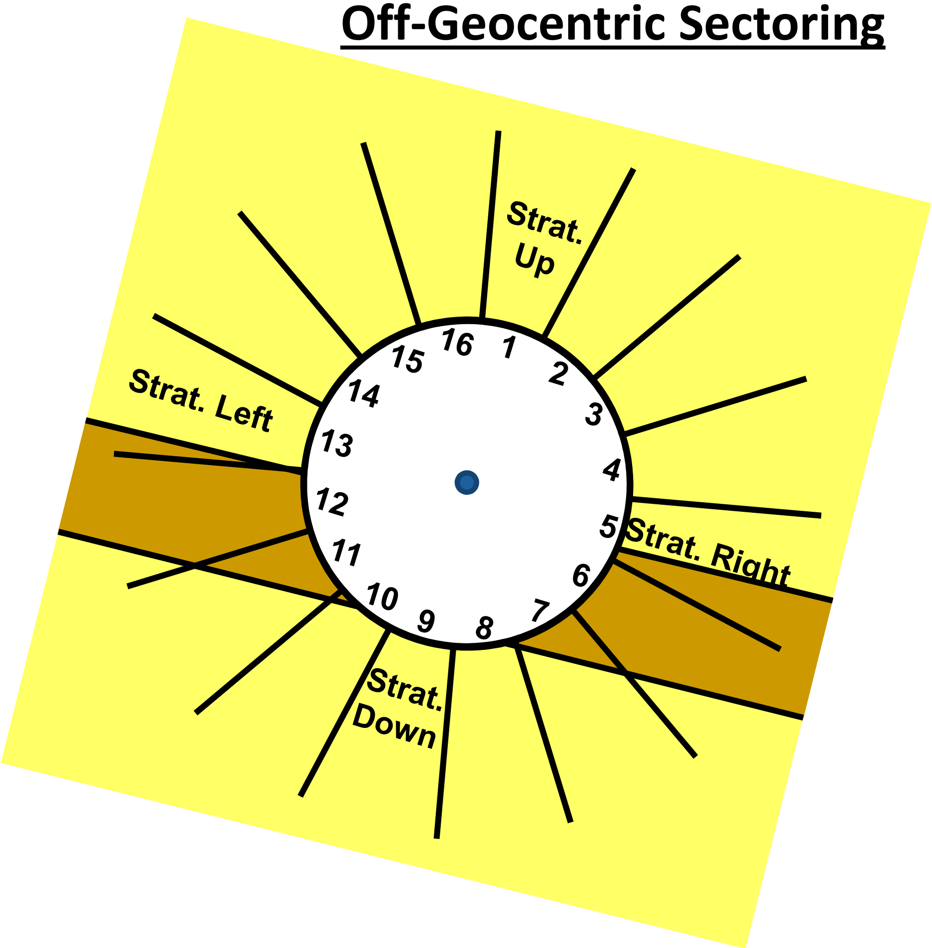
Off-Geocentric Sectoring



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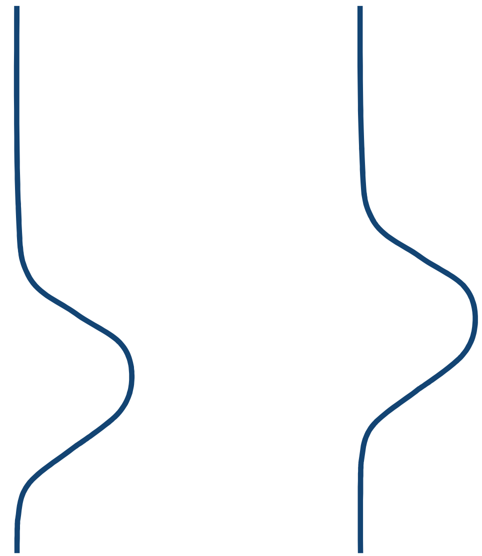
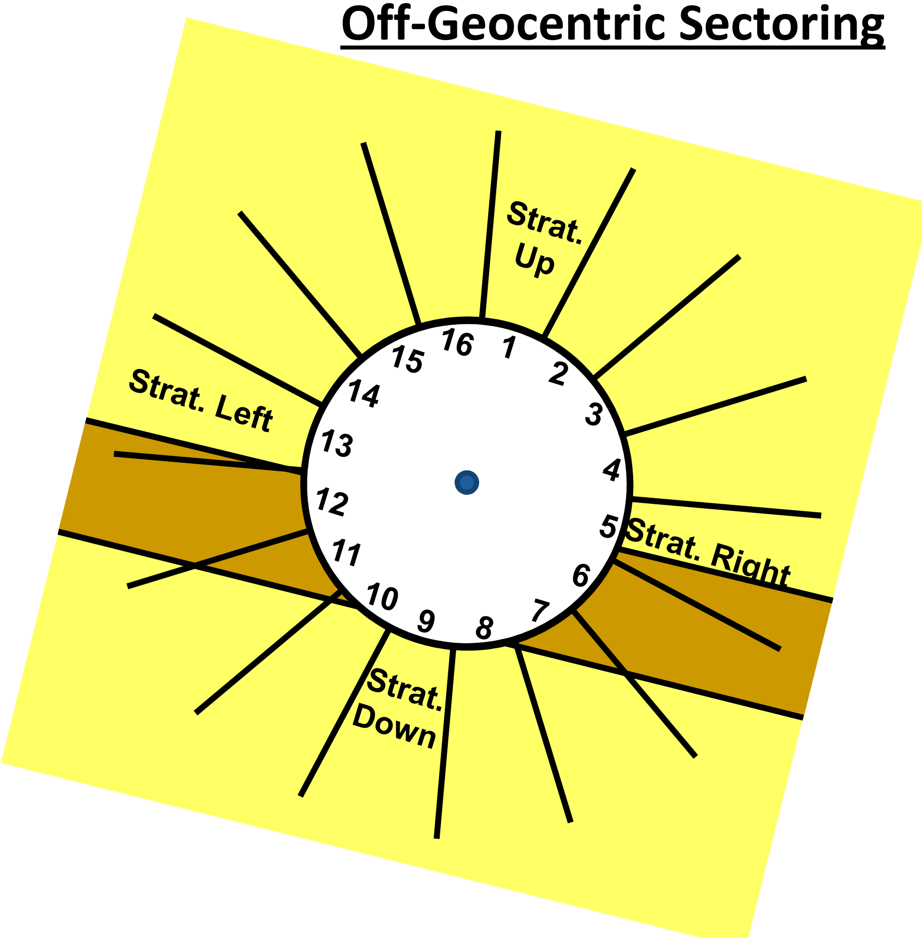
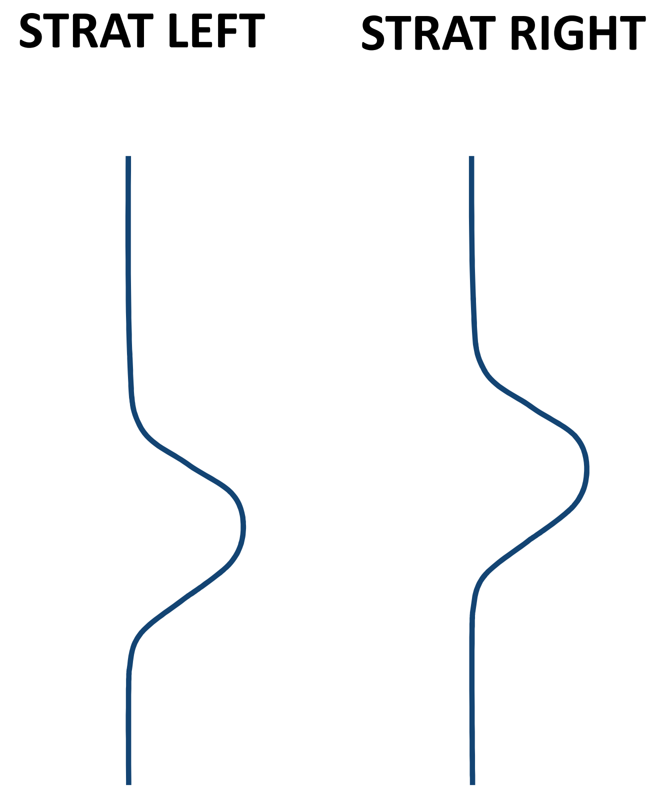


Geocentric Sectoring
Adjusting to Geologic Changes

DIPPING BED EXAMPLE

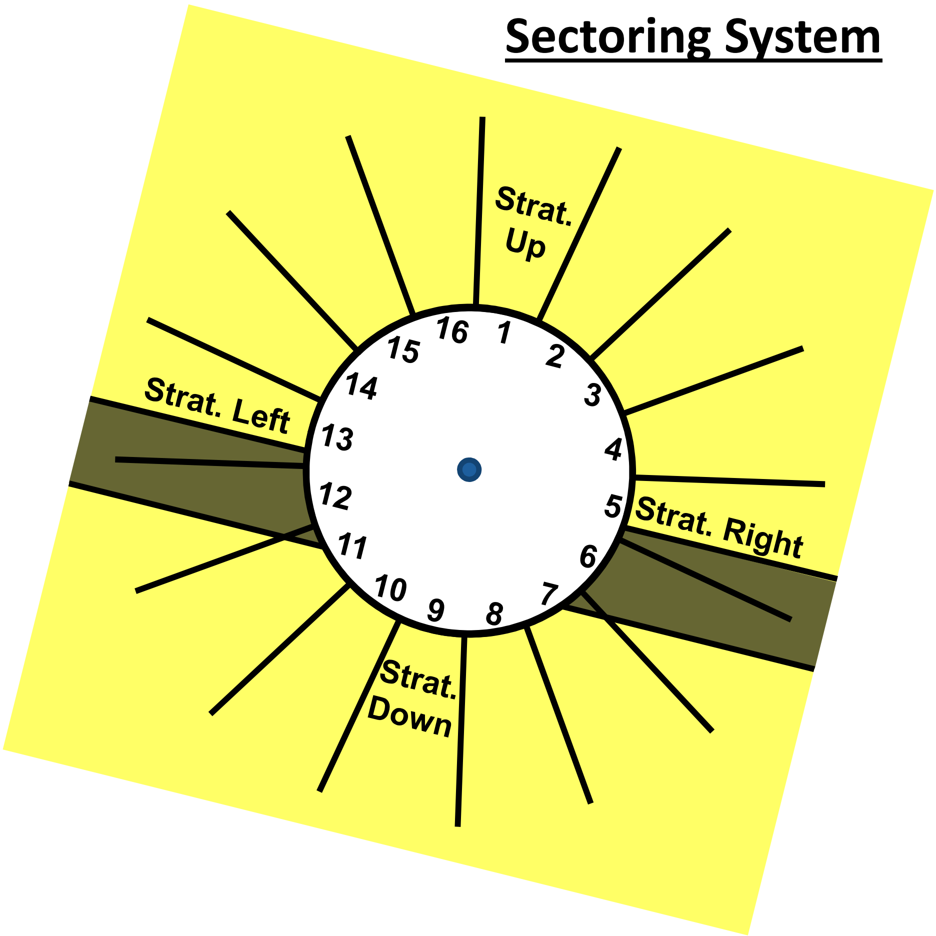
Formation Change causing
Off-Geocentric Sectoring





Geocentric Sectoring
Adjusting to Geologic Changes

Return to Geocentric
<u>Sectoring System</u>



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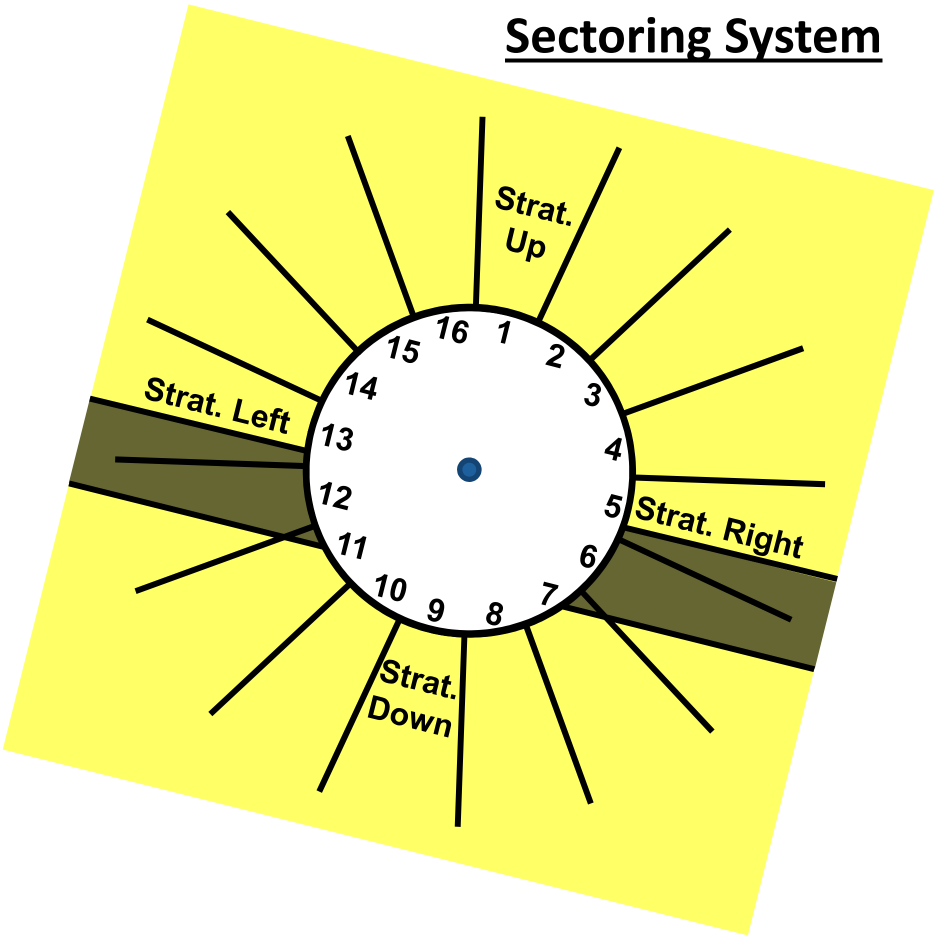
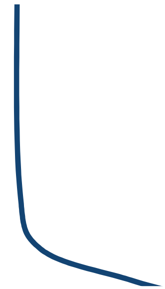
Geocentric Sectoring
Adjusting to Geologic Changes

Return to Geocentric
<u>Sectoring System</u>



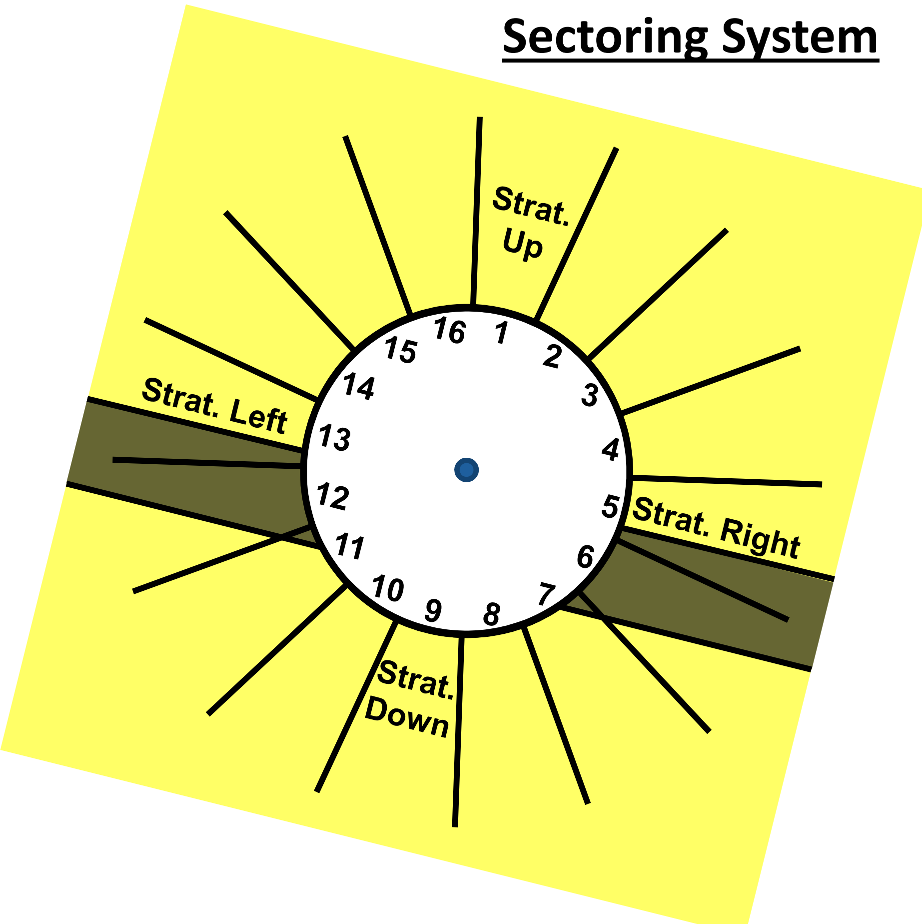
STRAT LEFT

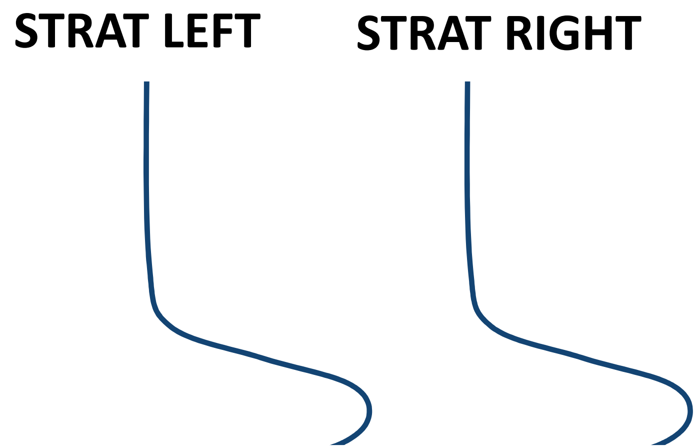
STRAT RIGHT



Geocentric Sectoring
Adjusting to Geologic Changes

Return to Geocentric
<u>Sectoring System</u>





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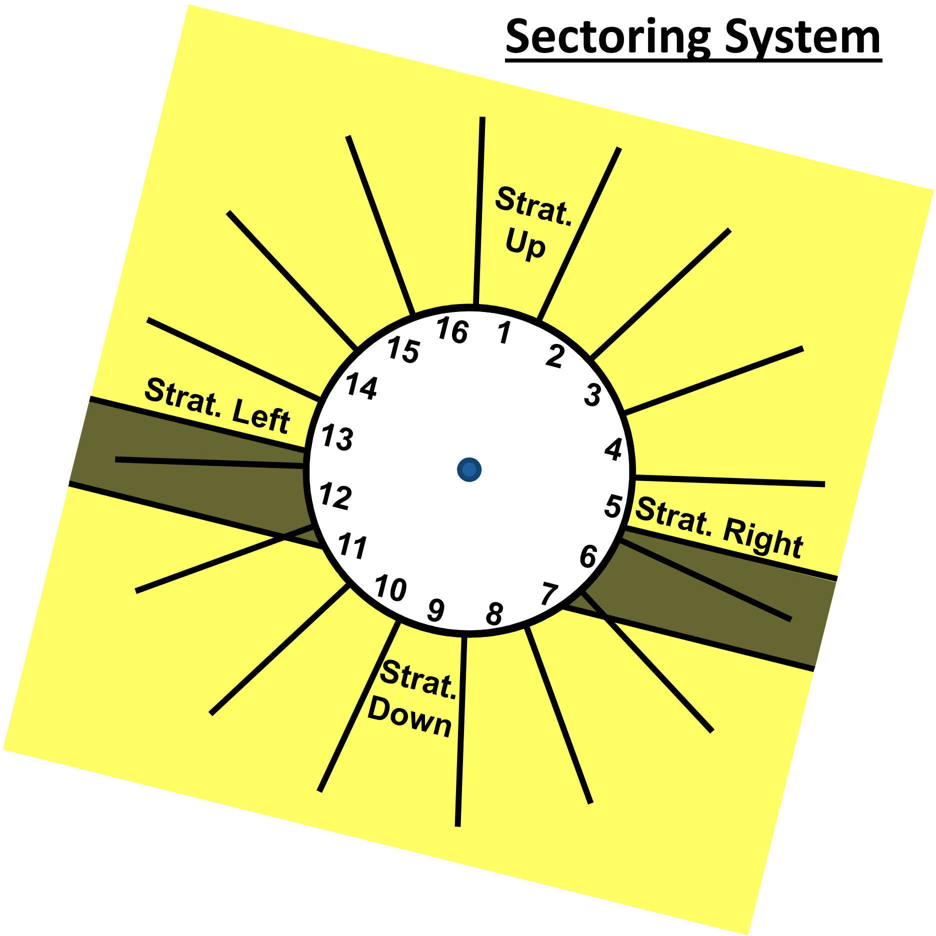

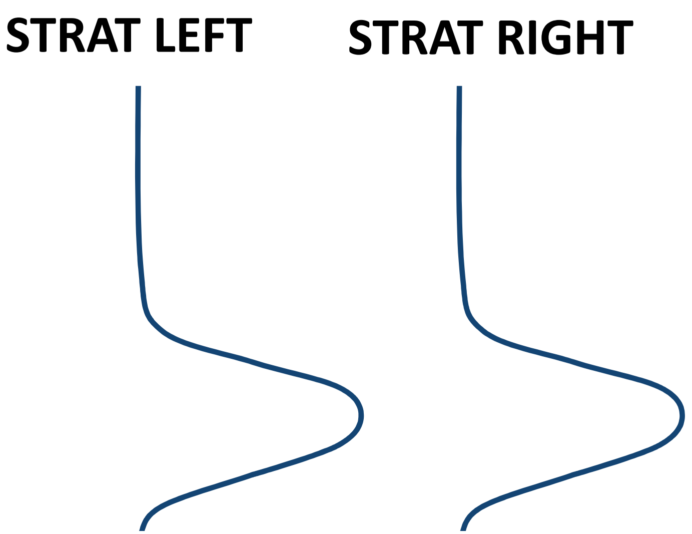

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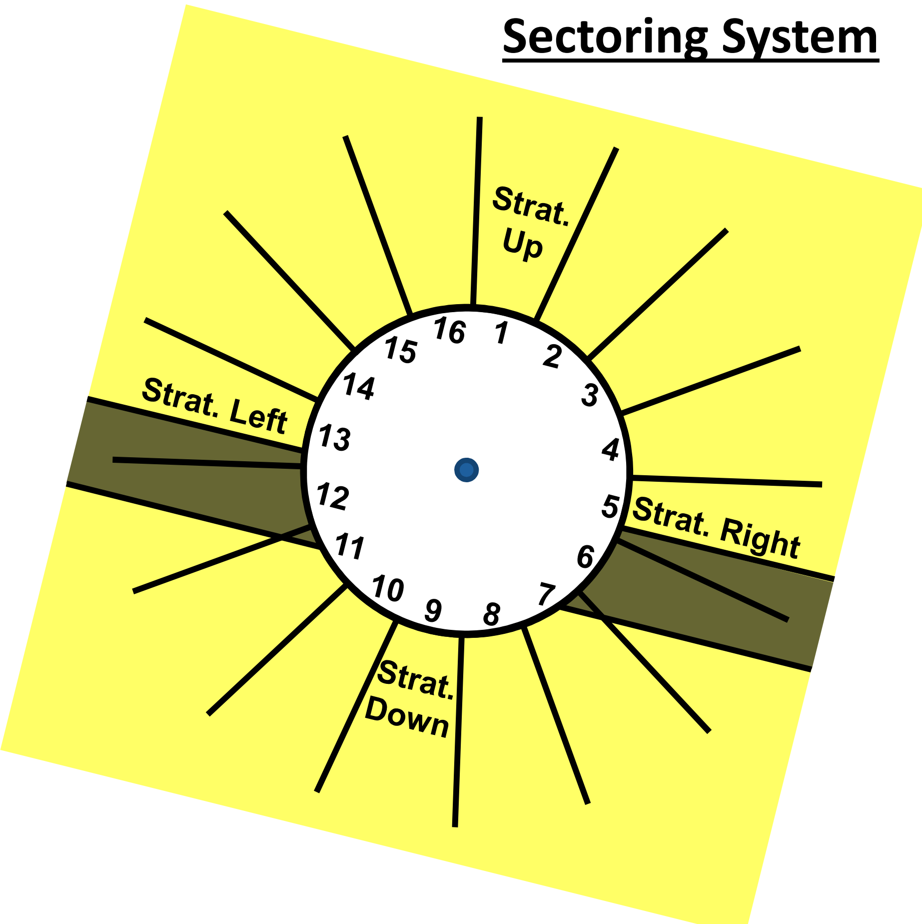

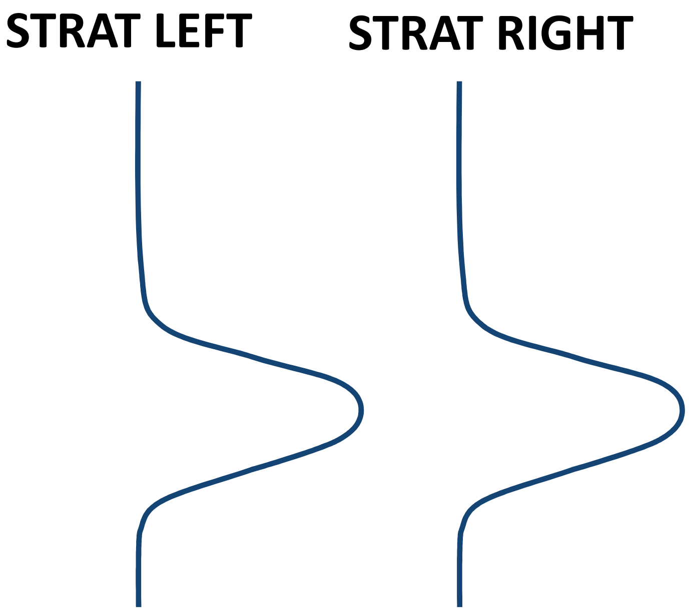

Geocentric Sectoring
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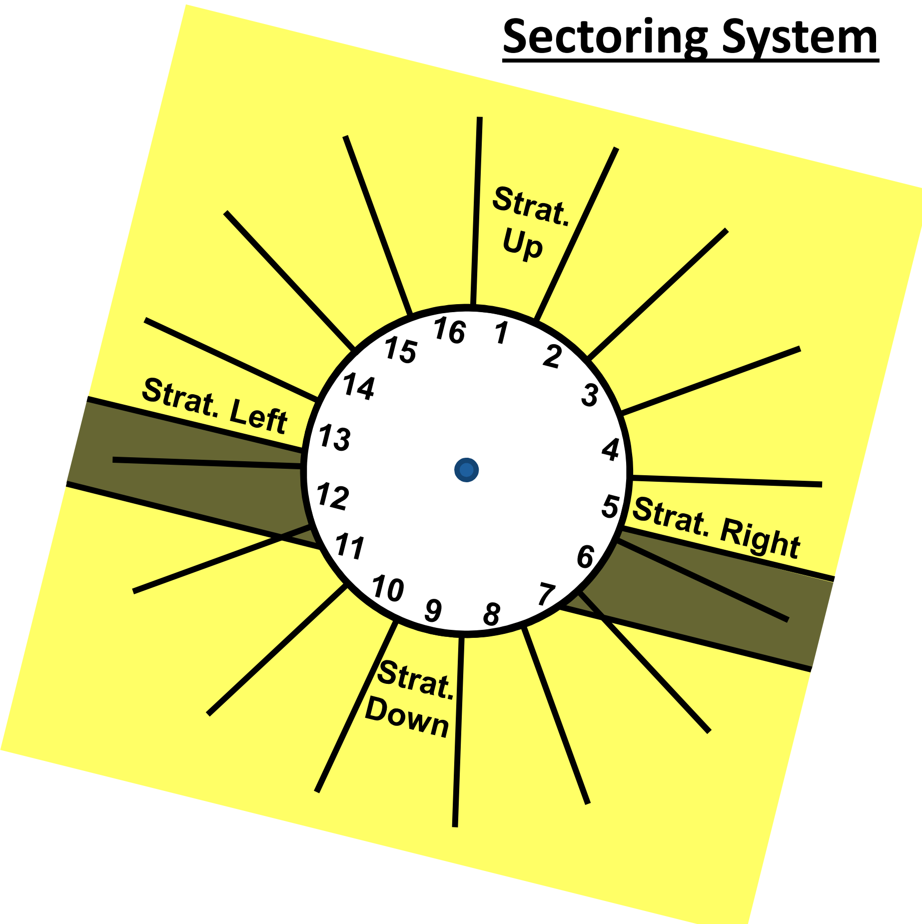

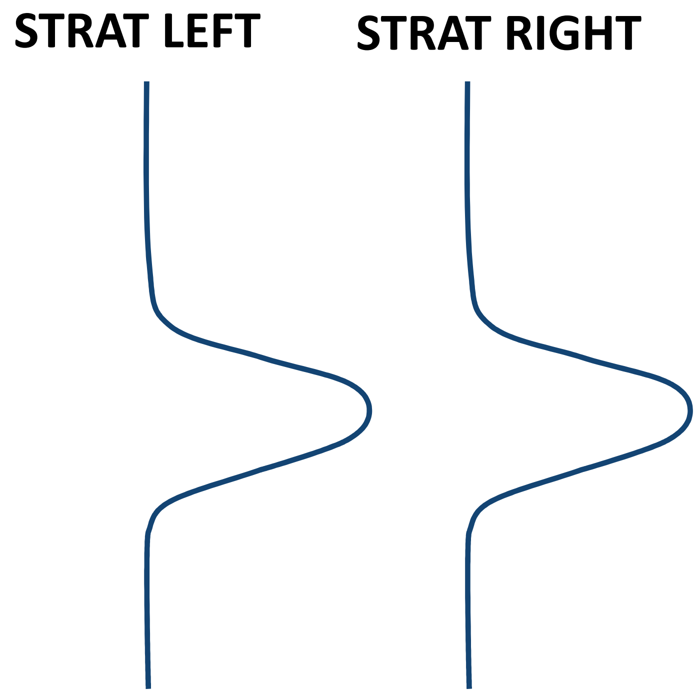

Summary and Conclusions

Geocentric Sectoring allows for:

- *Earlier Bed Boundary Detection*
  - *Enhanced Reservoir Navigation*
- *Refined RDIP Calculation*
  - *Enhanced Structural Analysis*
- *Refined RSTRIKE Sector Curve Extraction*
  - *Highest Resolution Curve for Enhanced Petrophysical Analysis*