STONELEY REFLECTION ANALYSIS FOR FRACTURE DETERMINATION IN BOREHOLES

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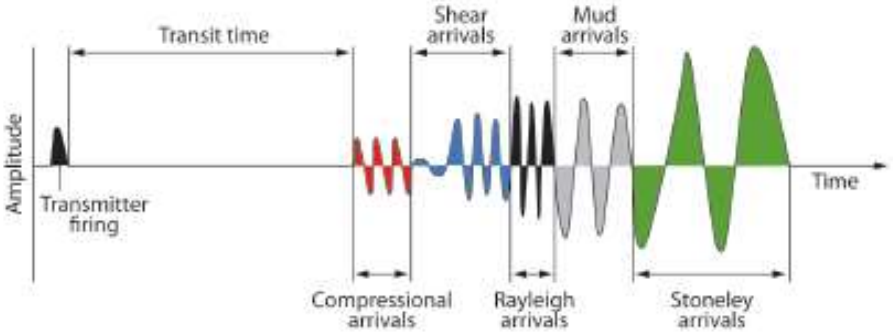
Outline

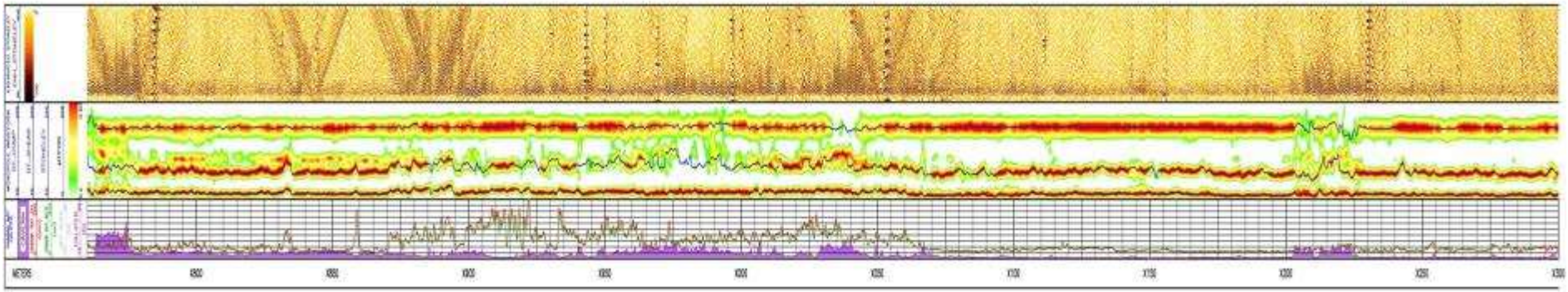
- **Introduction**
- **Full wave sonic tools & acoustic wave types**
- **Borehole Stoneley waves**
- **Stoneley wave Attenuation & Reflection**
- **Stoneley Reflection Analysis**
- **Field examples**
- **Conclusion**

Introduction

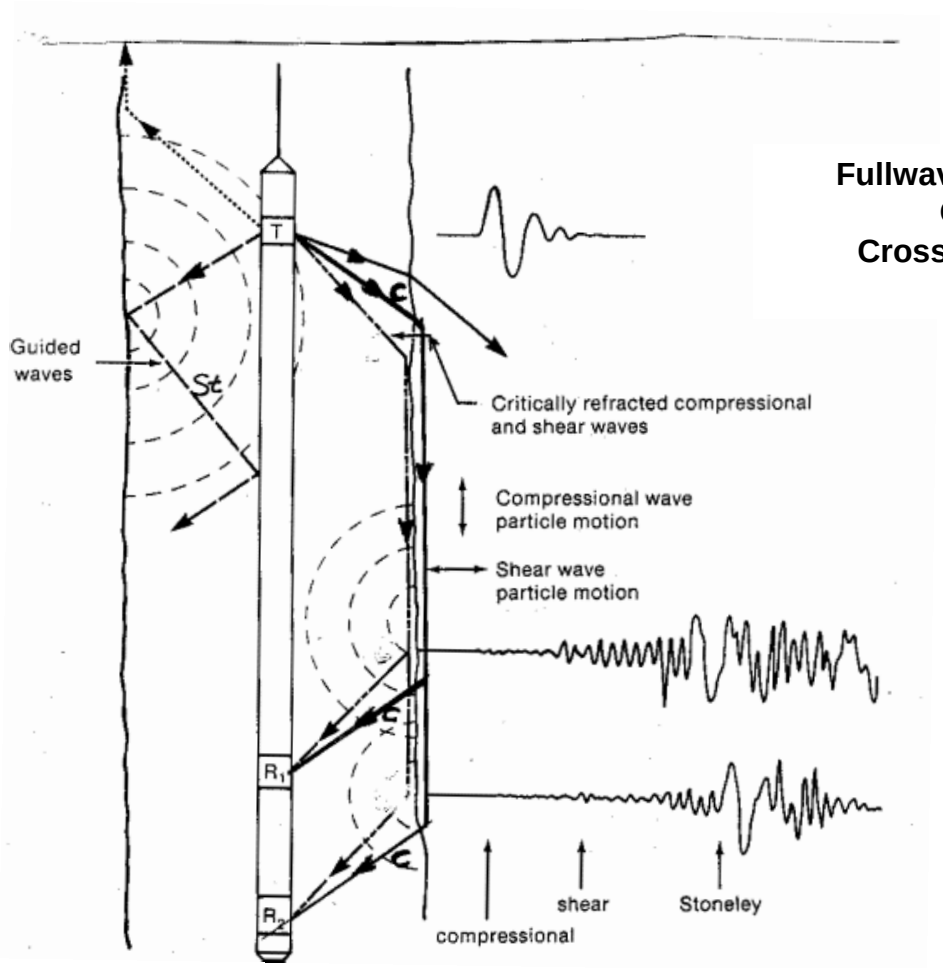
- **Acoustic borehole logging since the 1950s**
- **Full waveform measurement**
  - -P, S, Stoneley waves
- **Stoneley waves are good for:**
  - -Detecting fractures
  - -Aperture calculation
  - -Permeability calculation
- **Fractured carbonate reservoir evaluation**



http://en.wikipedia.org/wiki/Stoneley_wave



Full wave sonic tools



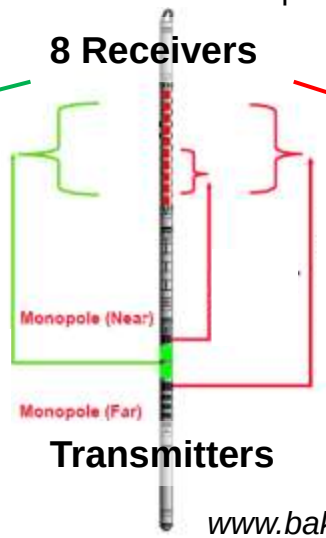
CRAIN'S PETROPHYSICAL HANDBOOK
http://www.spec2000.net/07-soniclog.htm

- XMAC (Baker) — Full waveform detection, Monopole – Dipole mode

8 Receivers

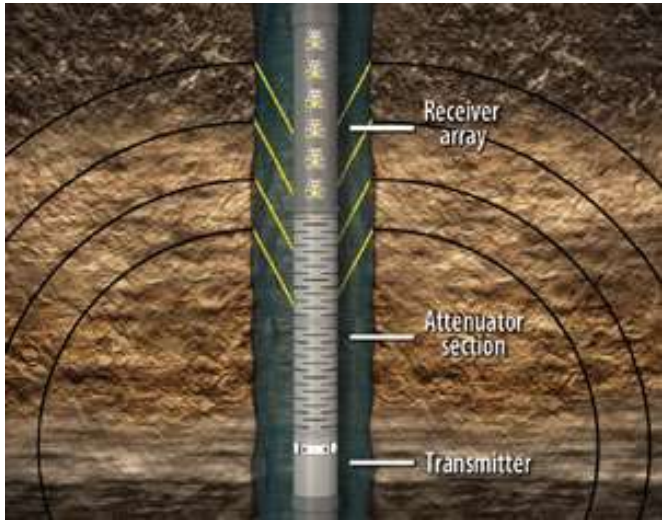
Fullwave Dipole Or **Cross-Dipole**

Fullwave Monopole Or **Mono DT 4 Rec**



Transmitters

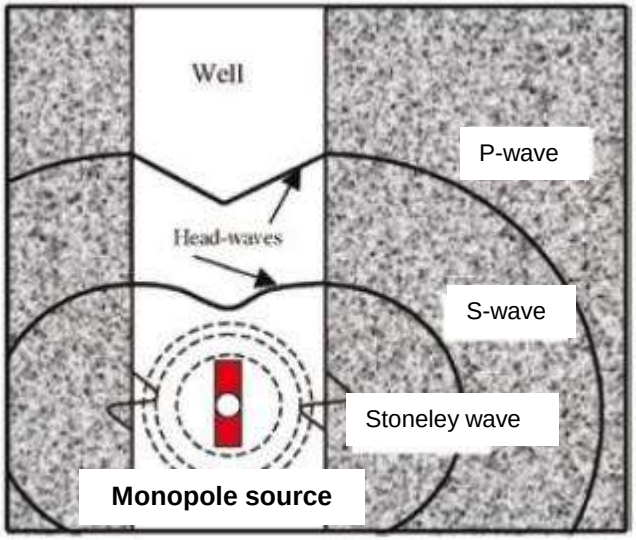
www.bakeratlasdirect.com



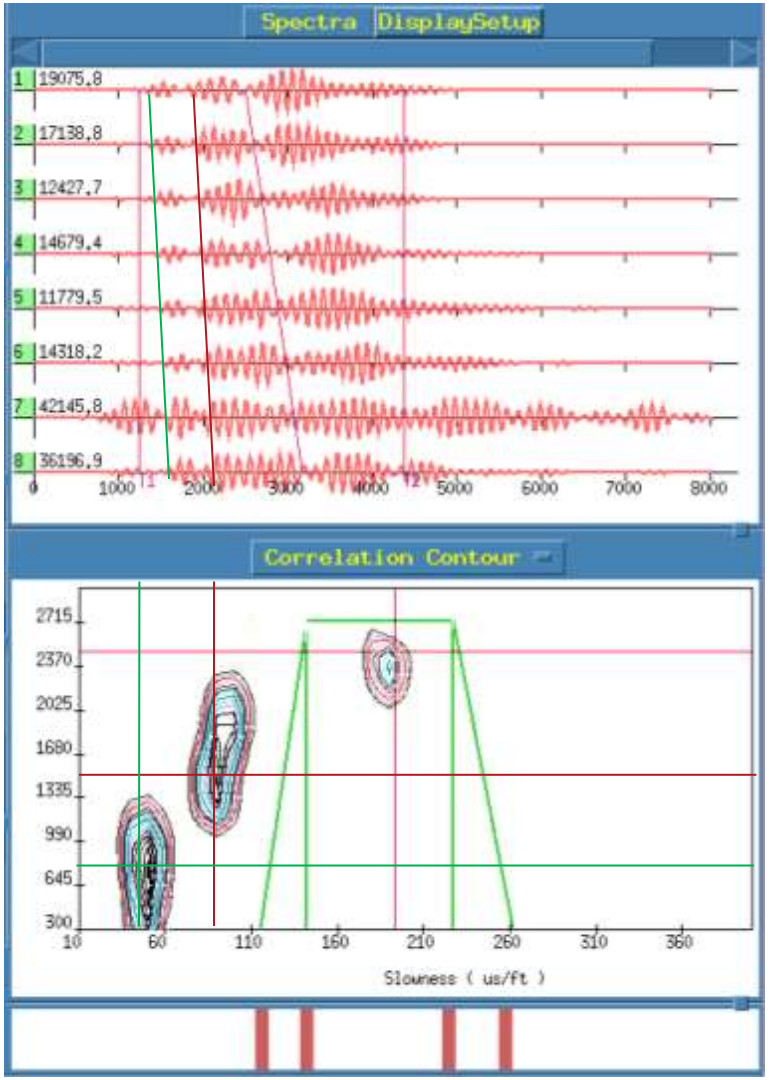
Acoustic wave types

- **Monopole measurement**
  - P-wave (Compressional wave)
  - S-wave (Shear wave)
  - Stoneley wave (guided tube wave)

For slowness determination, porosity and permeability calculation



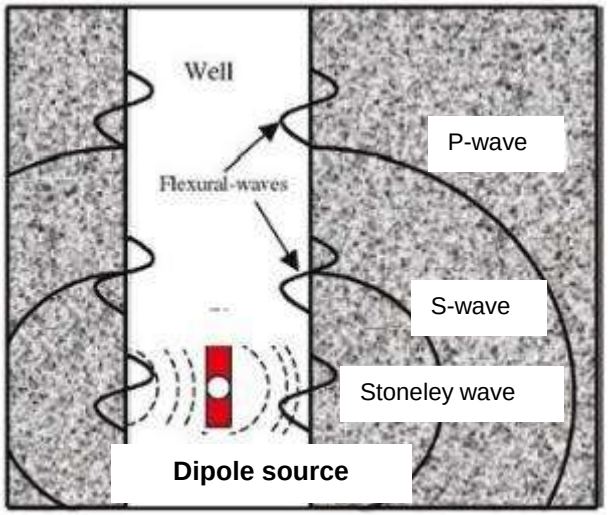
(Ávila–Carrera et al., 2011)



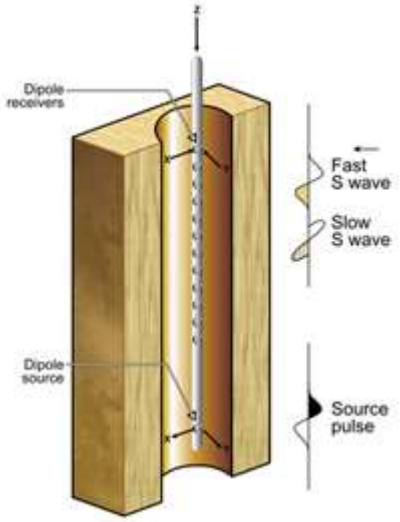
Acoustic wave types

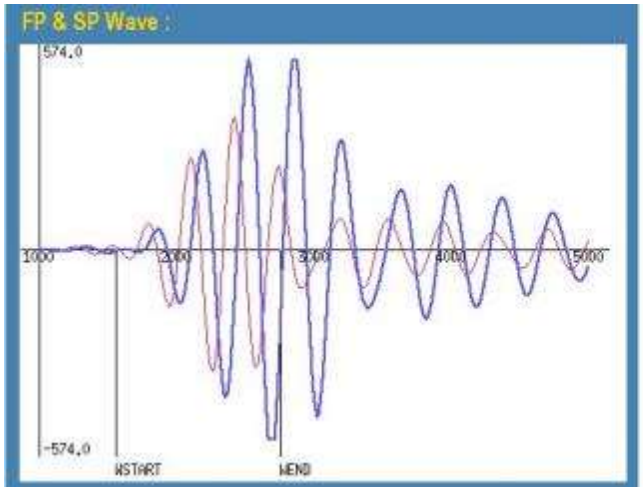
- **Dipole measurement**
  - Dipole XX Shear wave
  - Dipole XY Shear wave
  - Dipole YX Shear wave
  - Dipole YY Shear wave

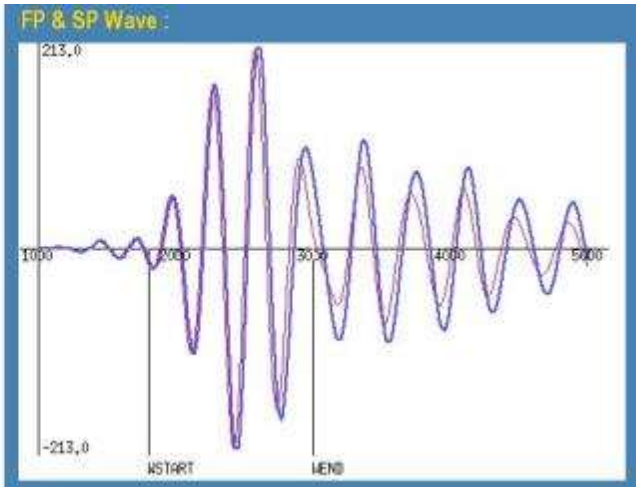
For azimuthal anisotropy detection



(Ávila–Carrera et al., 2011)

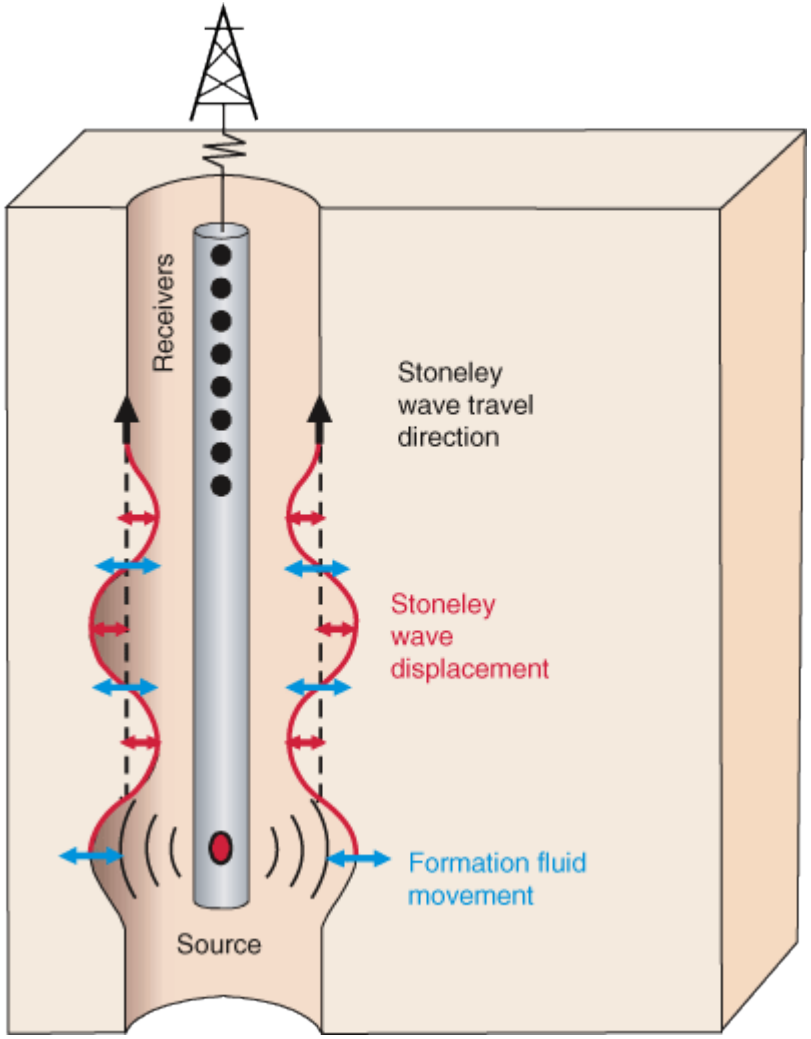






Borehole Stoneley waves – wave generation

- **Stoneley wave is a high-amplitude surface wave** (or interface wave)
- Also called **Tube wave or Stoneley tube wave**
- **Generated by a radial (symmetric) flexing of the borehole**
- **Arrive just after the shear wave or the fluid compressional wave**



http://en.wikipedia.org/wiki/Stoneley_wave

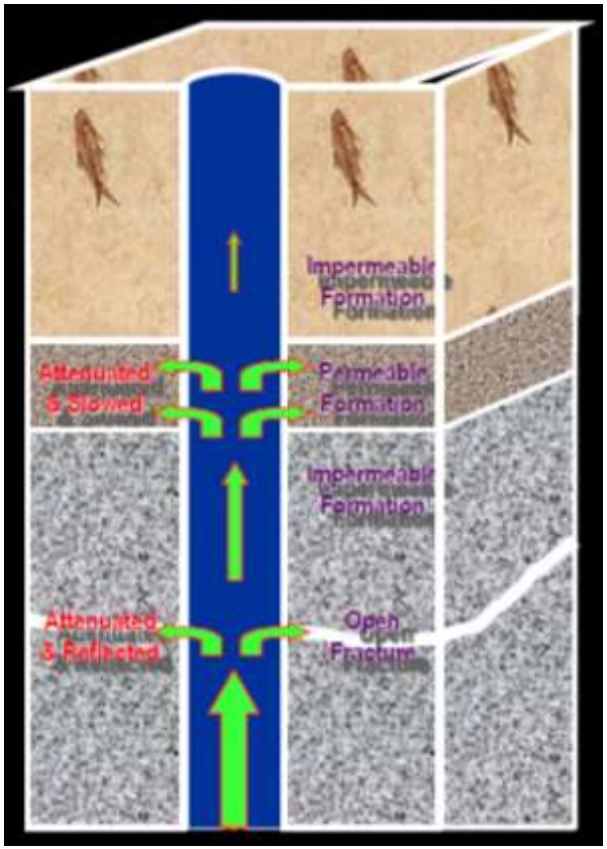
Borehole Stoneley waves – wave propagation

- **Propagate at low frequencies along the fluid-rock interface at the borehole wall**

→ **Sensitive to the rock properties adjacent to the borehole wall**

→ **Amplitude depends on the permeability of the rock, among other things**

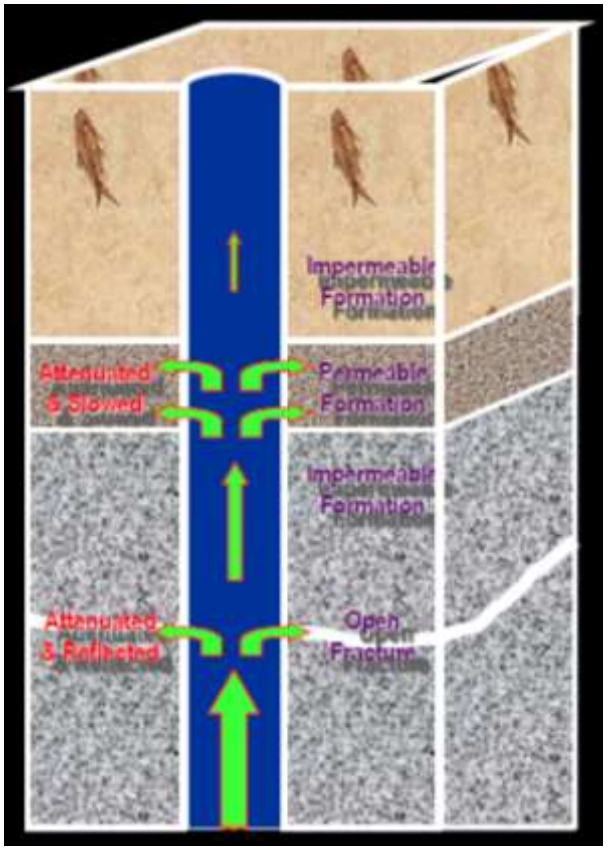
- **The wave guide is the annulus between the logging tool and the borehole wall**



(Borland , 2014)

Borehole Stoneley waves – wave characteristics

- **Stoneley wave in slow formations is slightly dispersive (low frequency arrive faster than high frequencies)**
- **in fast formations it is slightly reverse dispersive (high frequency arrives first)**
- **Stoneley energy loss due to**
  - -Washout
  - -Discontinuous fracture
  - -Bedding
  - -Thin gas sand



(Borland , 2014)

Borehole Stoneley waves – wave characteristics

- **If there is no permeability**

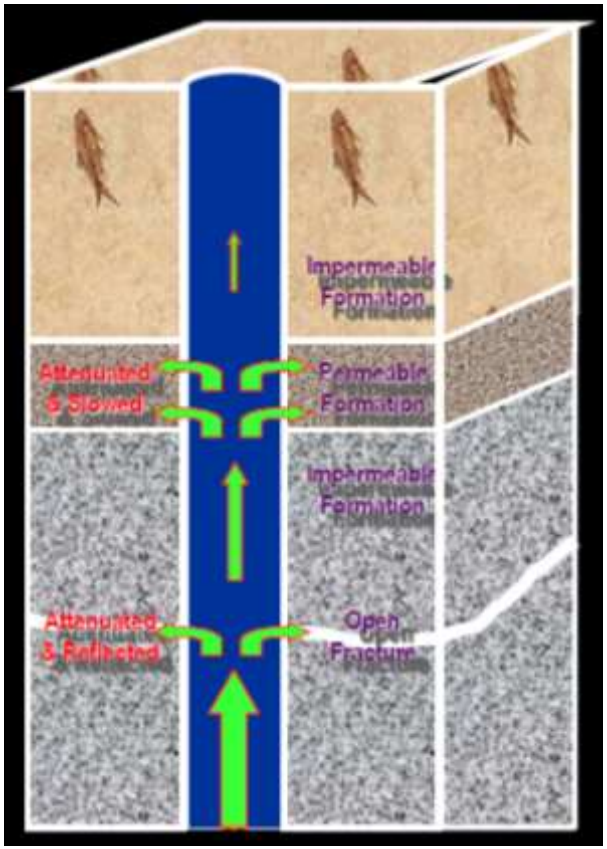
  - Slowness will be dependent on the mechanical properties of the rock and mud properties

- **Intergranular Permeability:**

  - Increasing slowness
  - Energy loss

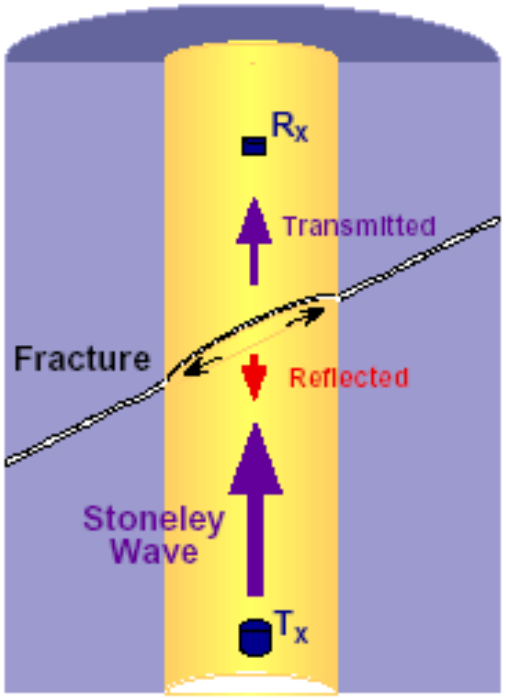
- **Fracture Permeability:**

  - „Reflects" Stoneley wave = Stoneley Reflection
  - Energy loss = Stoneley Wave Attenuation



(Borland , 2014)

Stoneley Wave Attenuation (Amplitude Reduction)



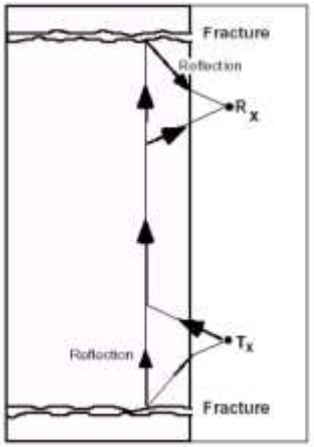
http://en.wikipedia.org/wiki/Stoneley_wave

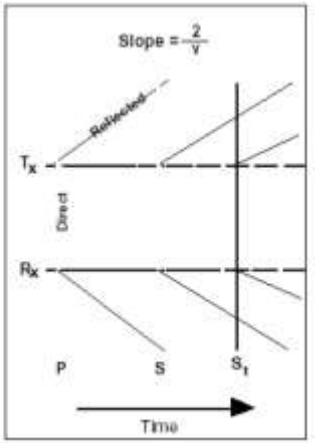
- **When an open fracture intercepts the borehole**
- **Stoneley causes well fluid to be pumped in and out of the fracture**
- **Energy is dissipated**

→ This results in the **attenuation of the Stoneley wave**

Stoneley Reflection

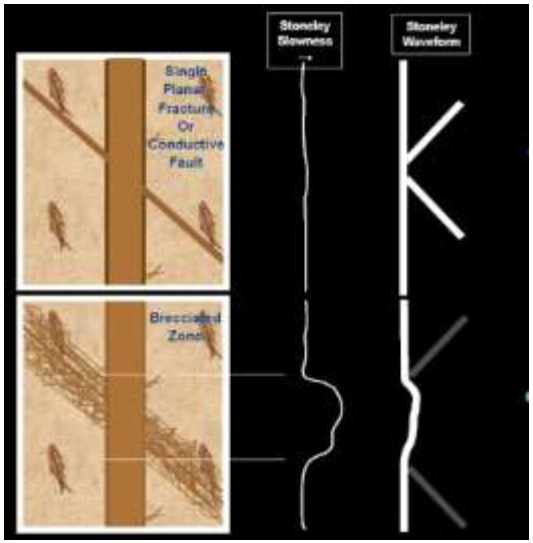
- **The time difference between the direct and reflected arrivals depends on the distance between the reflector and the fracture, and on the slowness in the non-fractured rock (block slowness)**
  - It changes linearly as the tool moves up closer to the fracture (nil when the receiver faces the fracture





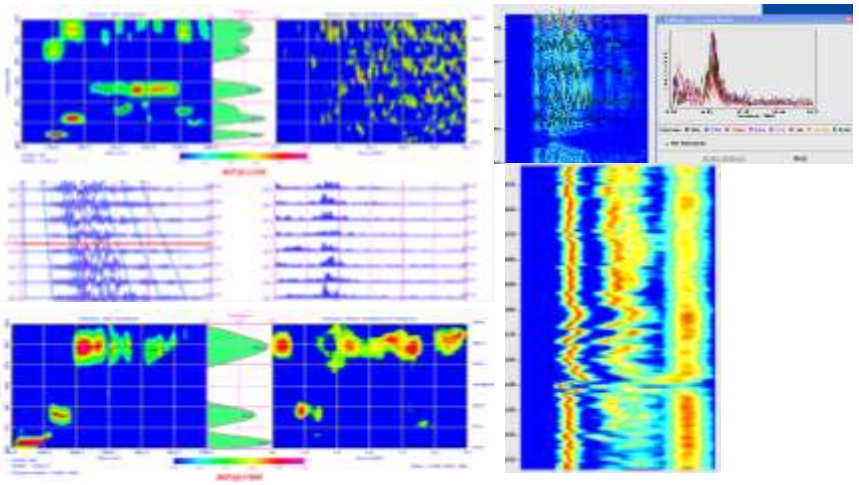
- A symmetrical effect occurs for a fracture located below the transmitter

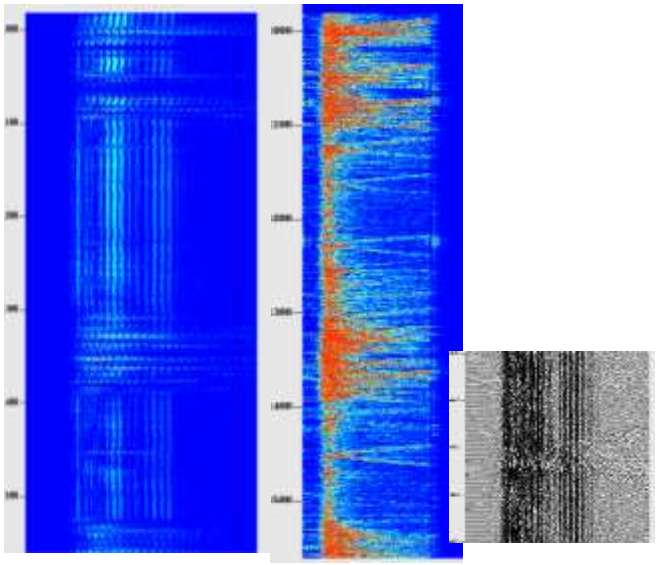
- This effect result in the **Chevron Patterns visible on VDL plots** in the Stoneley zone, after the direct signal has decayed

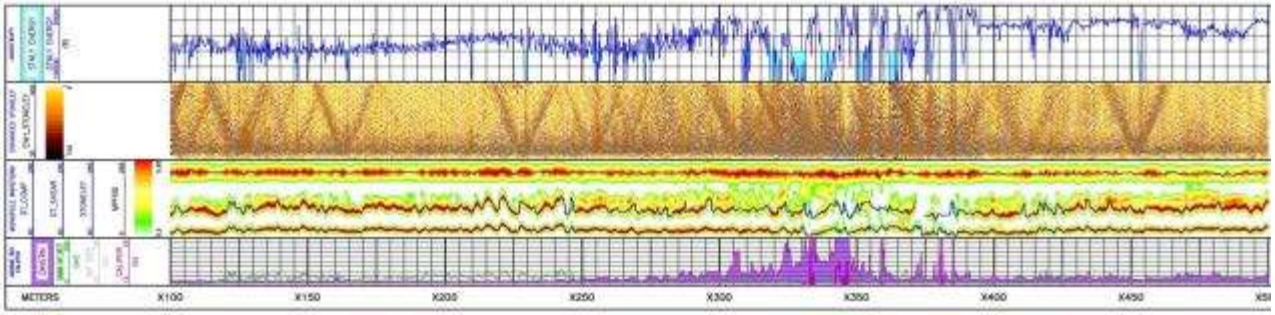


Stoneley Reflection Analysis

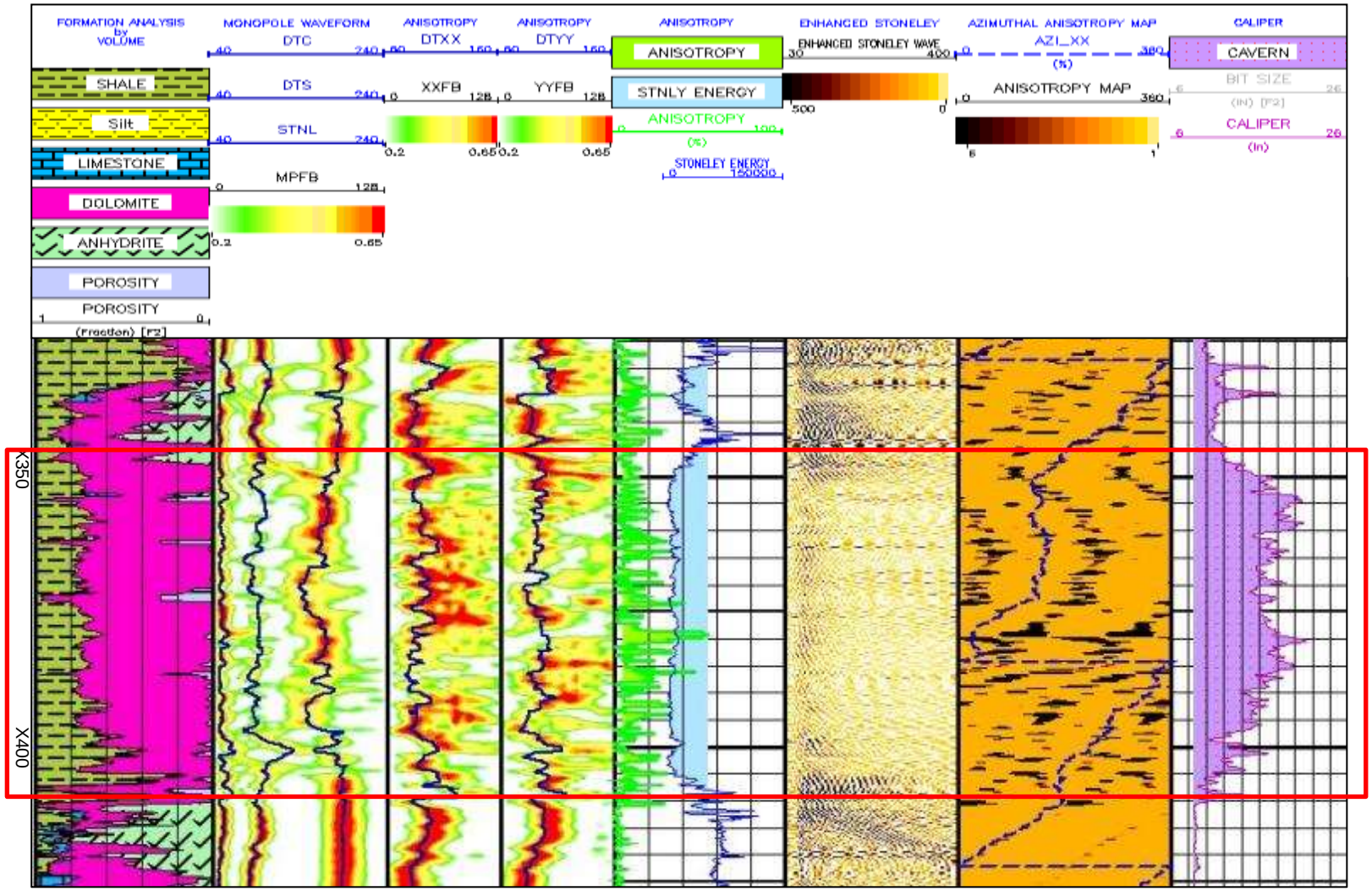
- **Wave separation (frequency, time and slowness filtering)**
- **Stoneley wave detection, enhancement**
- **Chevron detection**







Field example – **Cavernous zone**



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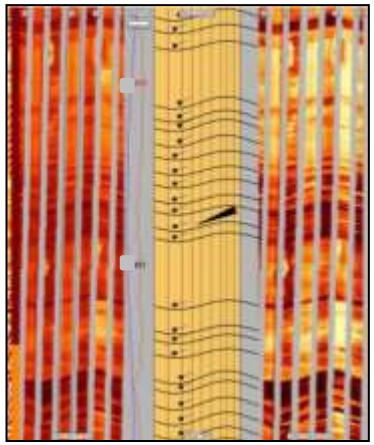
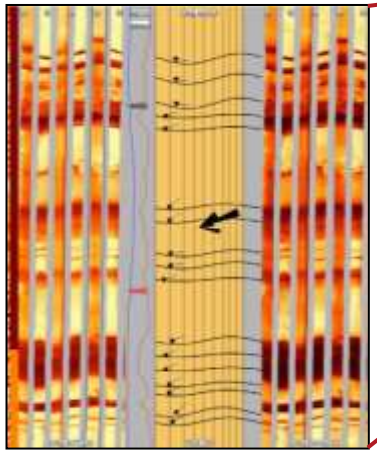
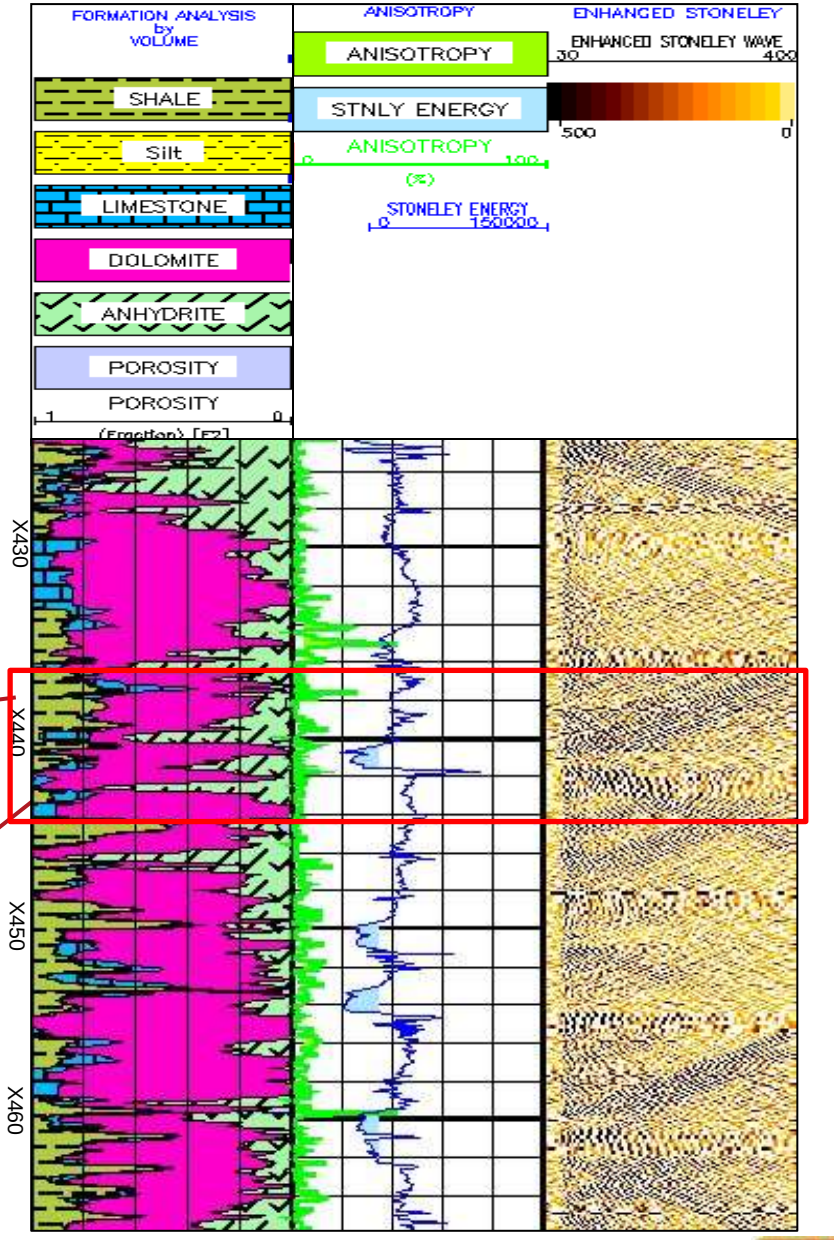
Field example
– Lithology changes

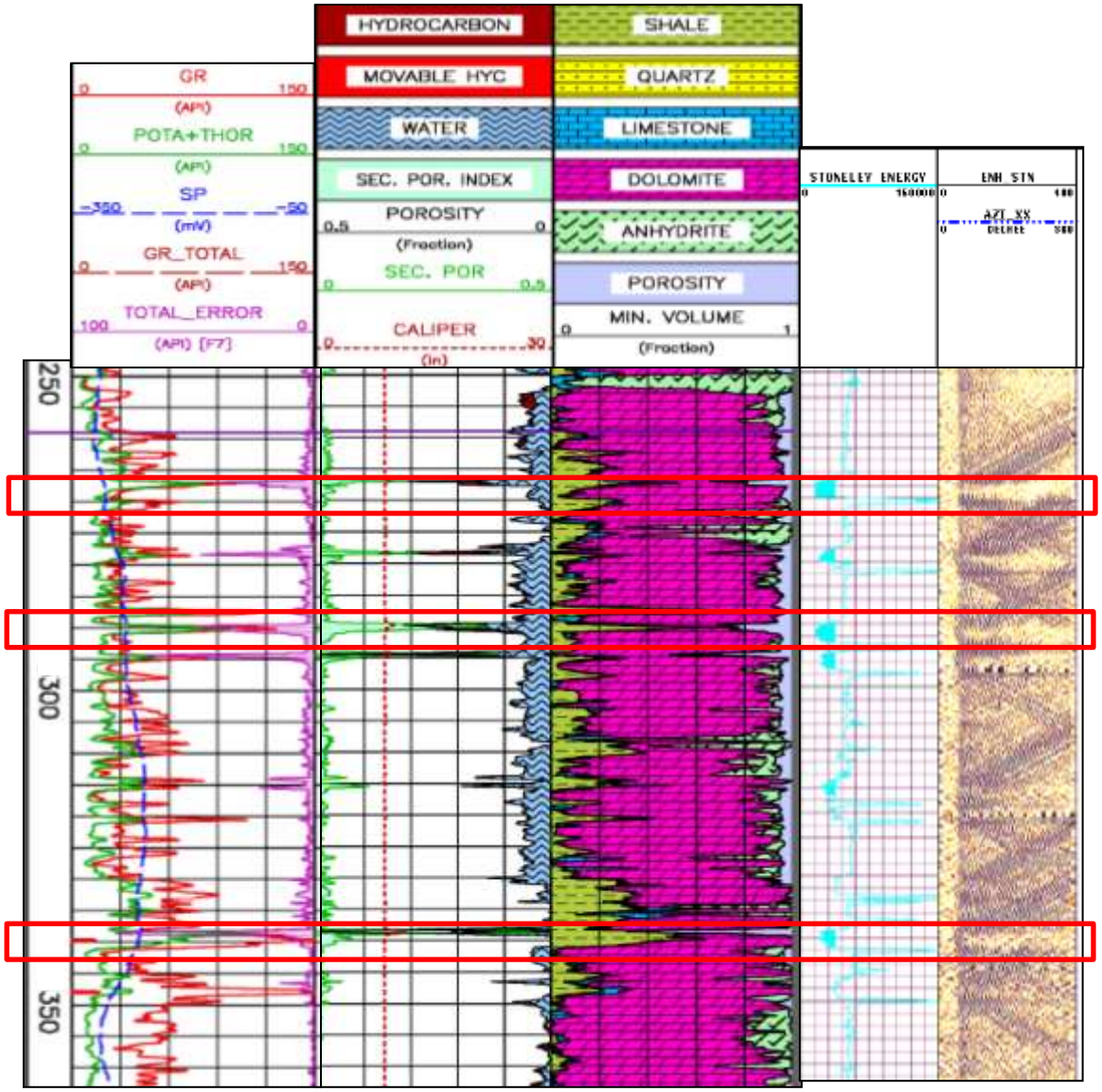




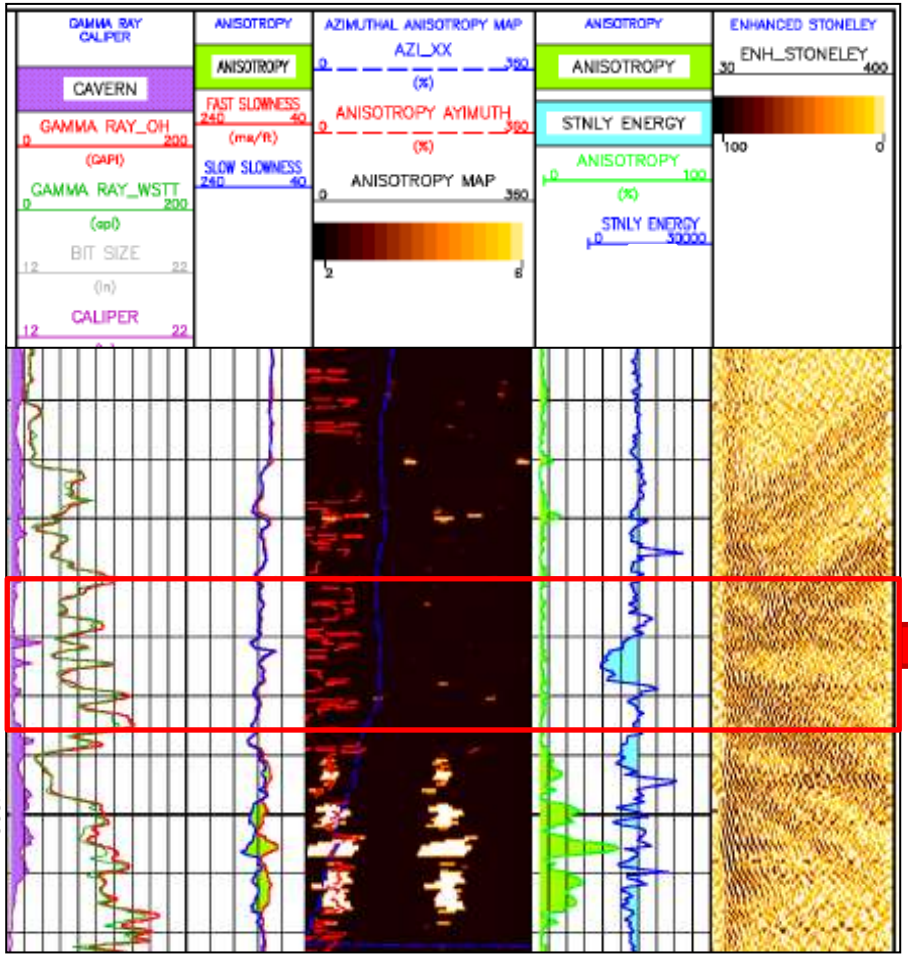
Bedding planes on image dipping to NE



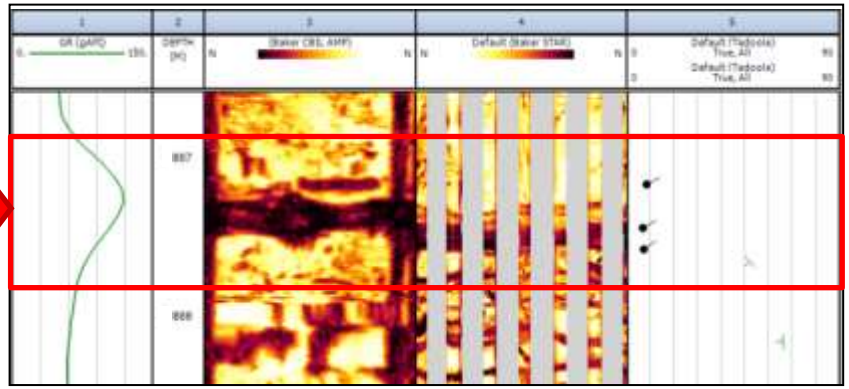
Field example – **Closed fractures**



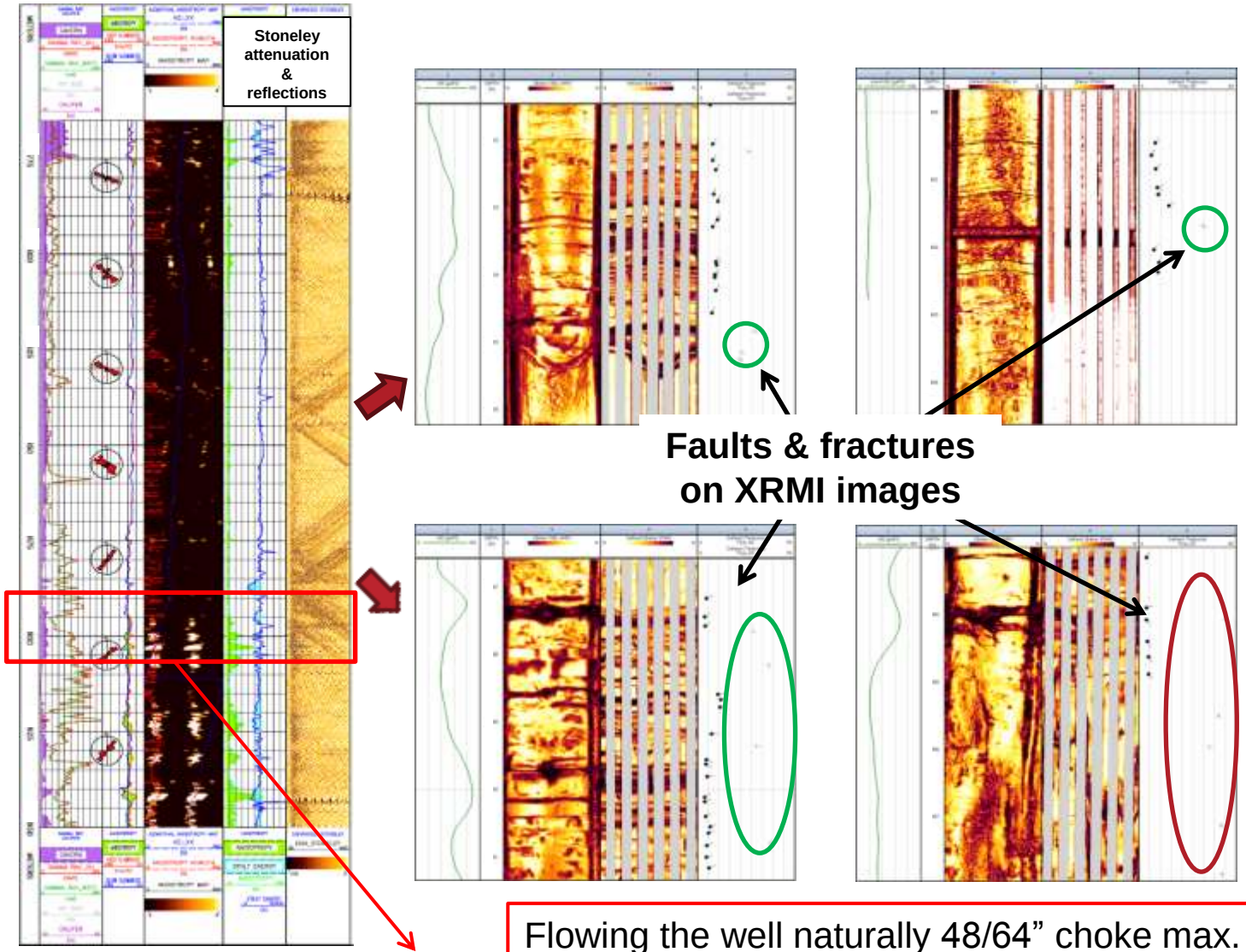
Field example – **Open fractures**



Open fractures
on XRMI image



Field example – **Faults and fractures**



Flowing the well naturally 48/64” choke max.
1900 bbl/day (~300 m^3/day) 100% oil and gas

Conclusion – Stoneley Reflection Analysis

- **Recently applied in MOL Plc.**
  - Sofware background required
  - Older logs will be evaluated
- **Reliable method but complementary information (image) required**
- **Useful method for fracture detection**
  - Esp. when the fracture is not visible on borehole image
- **Fractured zones = High permeability zones**
- **Cost-effective HC production from fractures**
- **High natural flow verified the method**


THANK YOU FOR YOUR ATTENTION!