KMS Technologies – KJT Enterprises Inc.

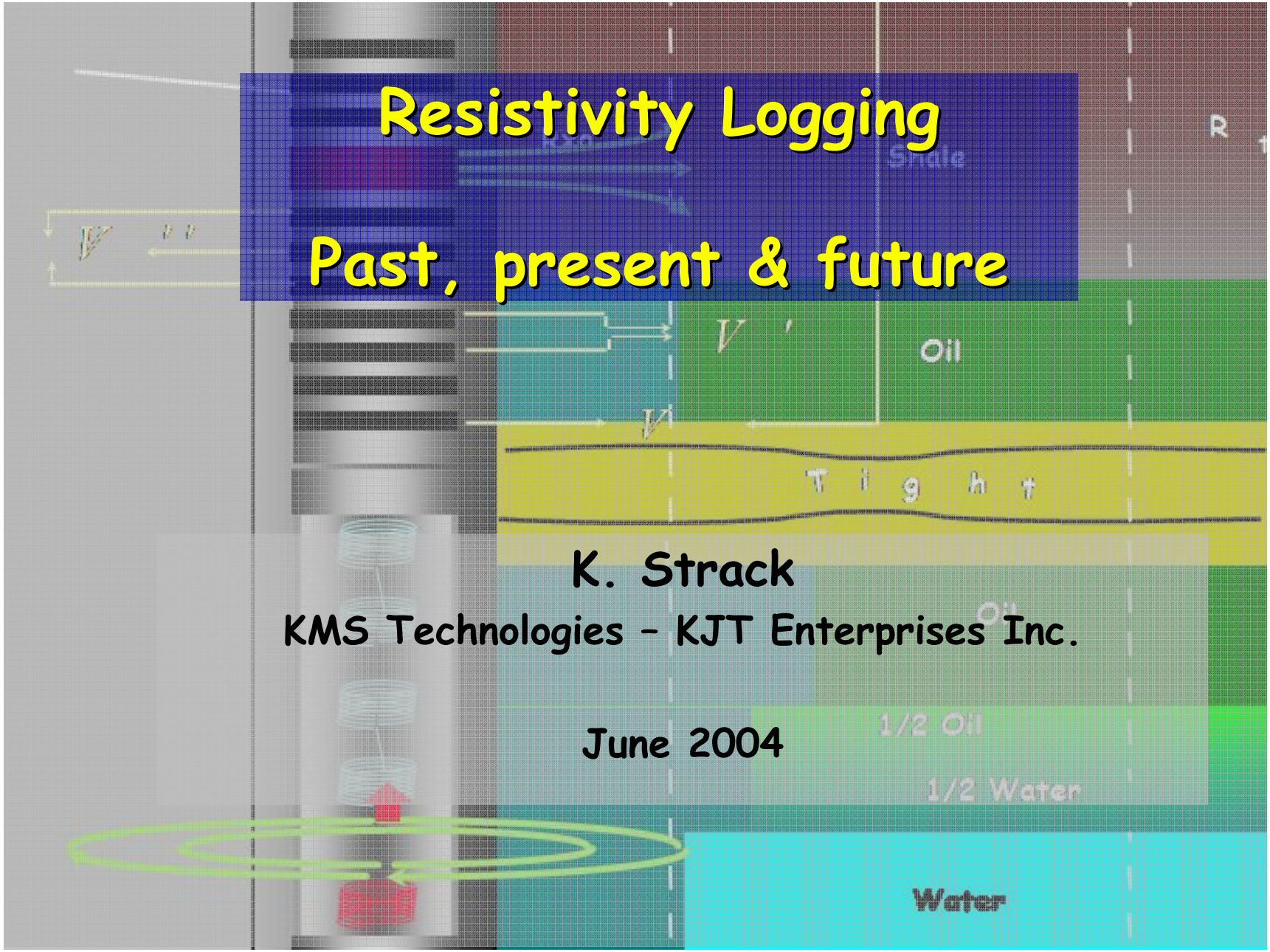
Presentation

Strack, K. – M.

2004

Resistivity Logging
Past, present & future

Society of Physics Students,
Technical Meeting, Dhahran, Saudi Arabia



Resistivity Logging

Past, present & future

K. Strack

KMS Technologies – KJT Enterprises Inc.

June 2004

Resistivity logging: Past, Present & Future

- Introduction
- Past
  - History
  - Older tools
  - Pitfalls
- Present
  - Overall concept
  - Improved tools
  - Innovative tools
  - Interpretation
- Future

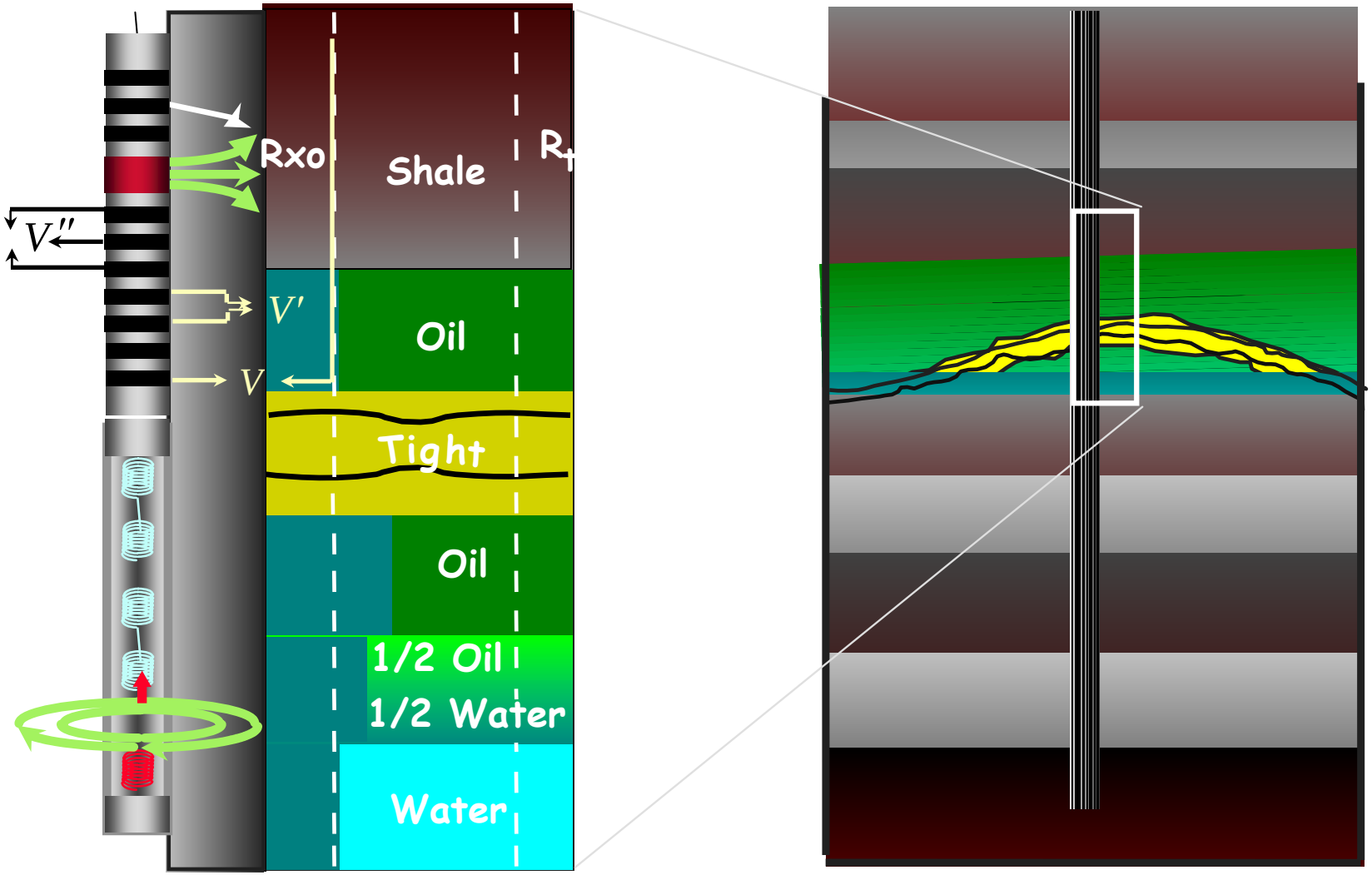
Resistivity logging: Past, Present & Future

- Introduction
- Past
  - History
  - Older tools
  - Pitfalls
- Present
  - Overall concept
  - Improved tools
  - Innovative tools
  - Interpretation
- Future

Objective

- Provide a resistivity logging snapshot
- Stay with wireline only (MWD later)
- Link past & future developments

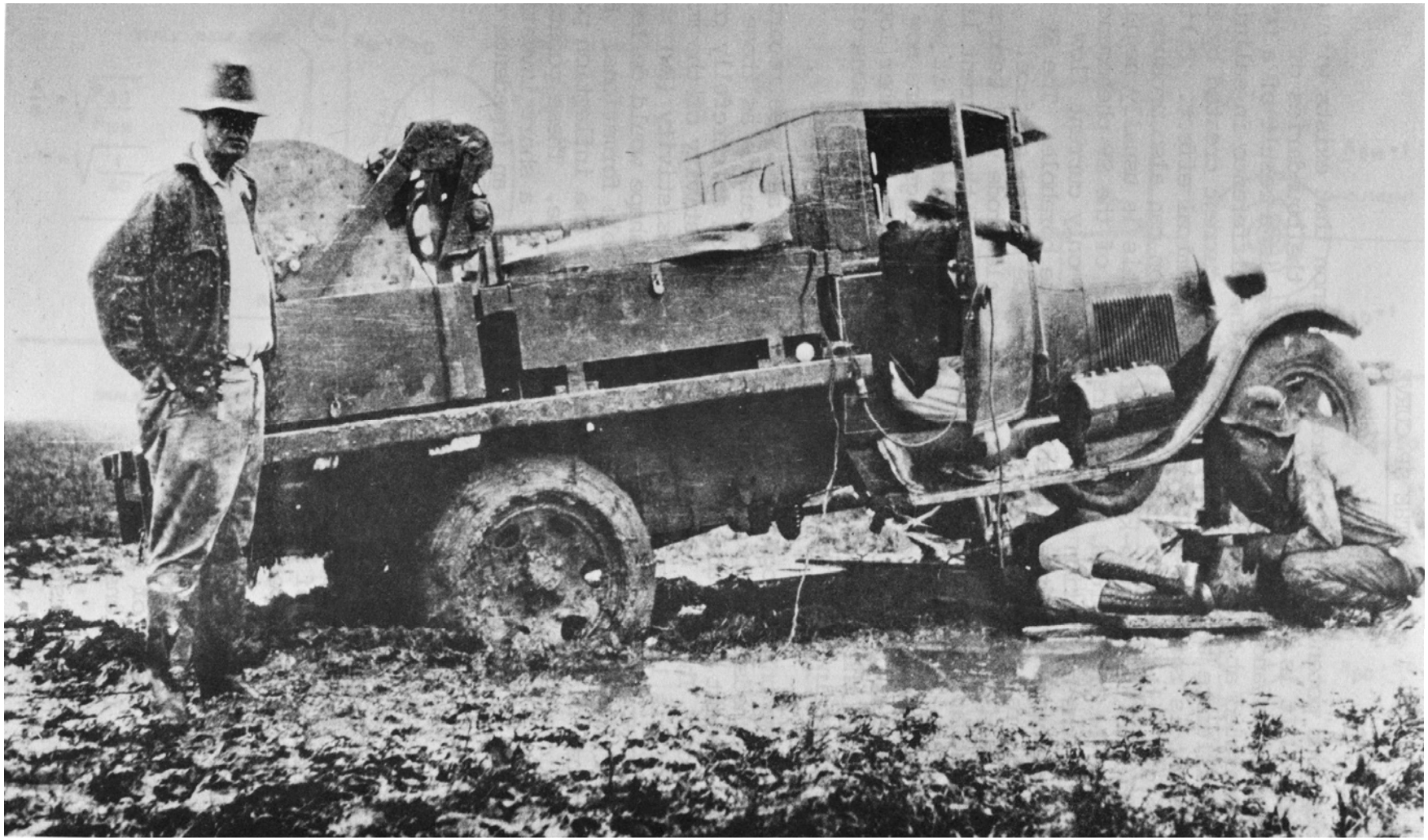
Oil - Resistivity relationship



Resistivity logging: Past, Present & Future

- Introduction
- Past
  - History
  - Older tools
  - Pitfalls
- Present
  - Overall concept
  - Improved tools
  - Innovative tools
  - Interpretation
- Future

The fun of ancient logging



After SPWLA, 1979

The Phases

- 1921 - 1927 Conceptual Phase
- 1927 - 1949 Acceptance Phase
- 1949 - 1985 Maturity Phase
- Since 1985 - Reinvention Phase

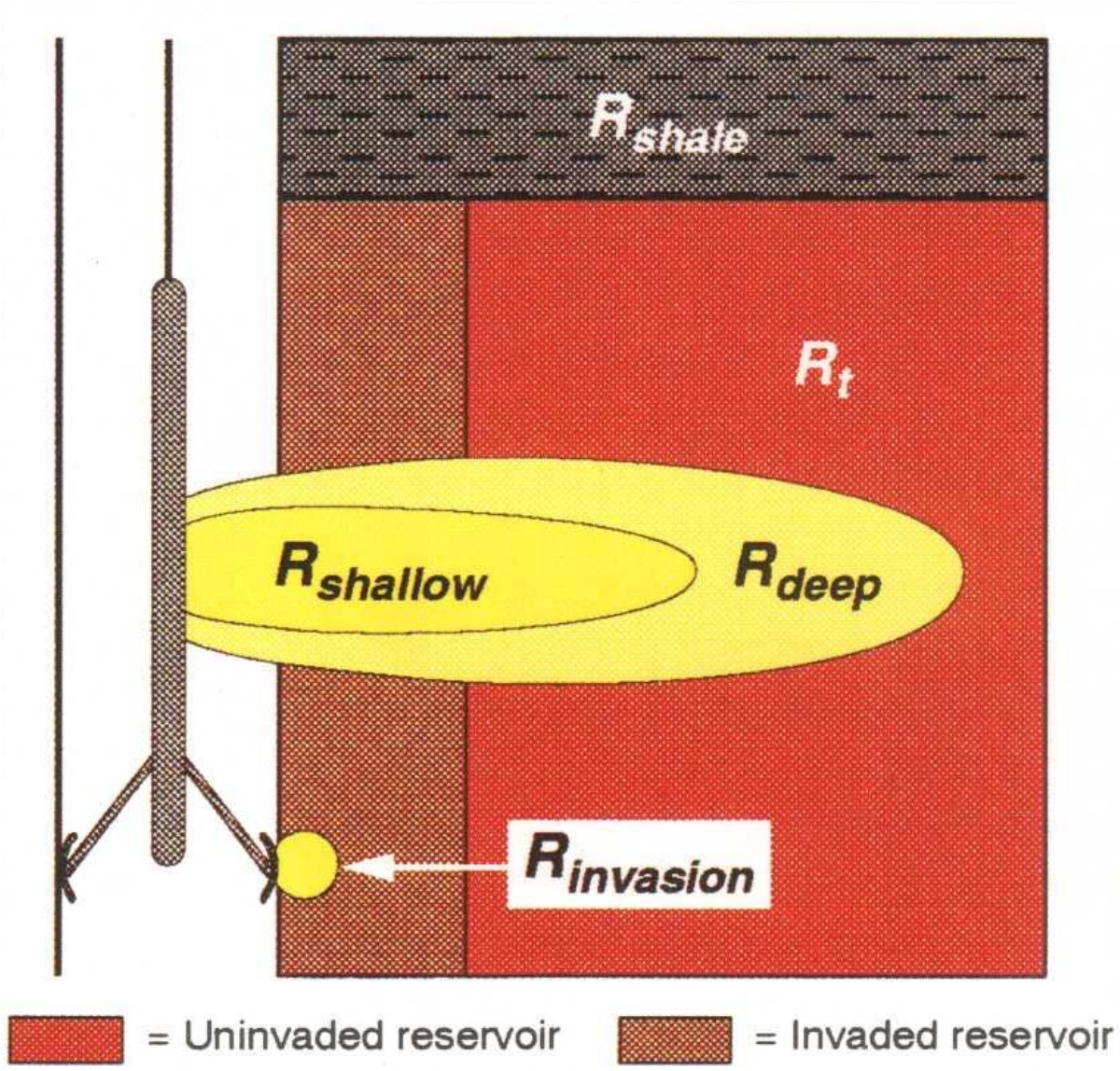
- Historically:
  - Schlumberger dominated (exceptions: MPI, EMI)
  - During 1990 Baker caught up and developed new tools (3DEX and TCR)

After Luthi 2001

Resistivity logging: Past, Present & Future

- Introduction
- Past
  - History
  - Older tools
  - Pitfalls
- Present
  - Overall concept
  - Improved tools
  - Innovative tools
  - Interpretation
- Future

Resistivity tools underlying principle

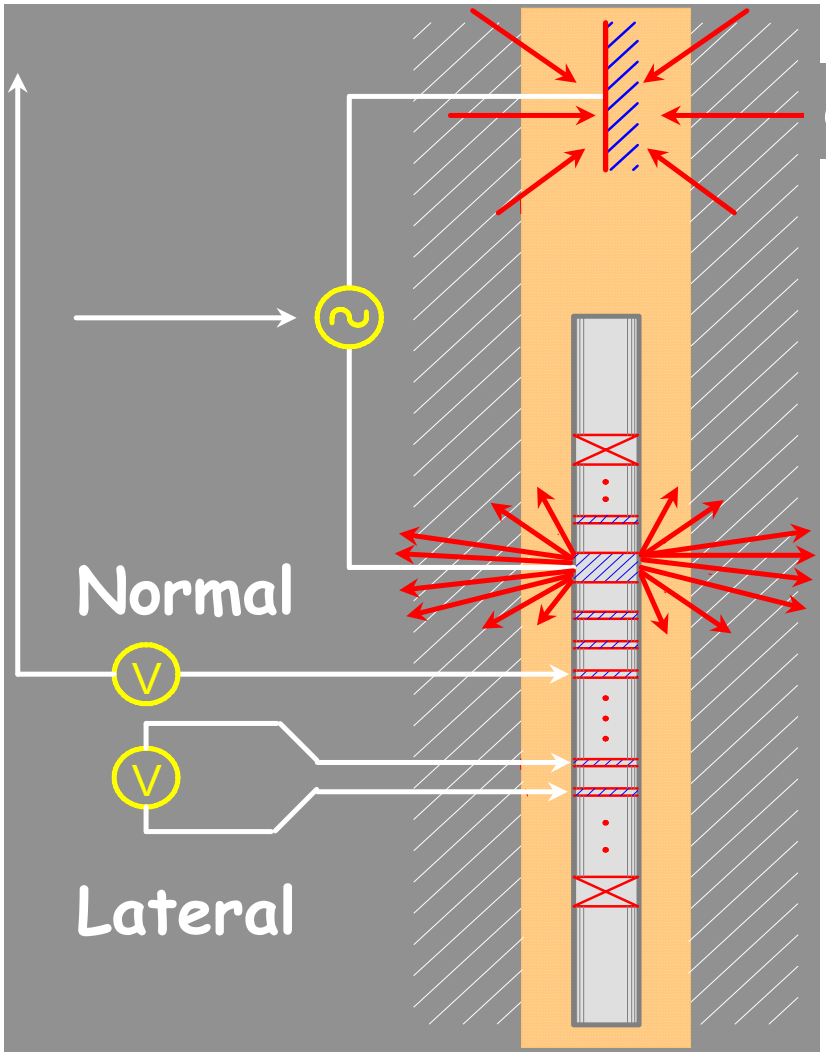


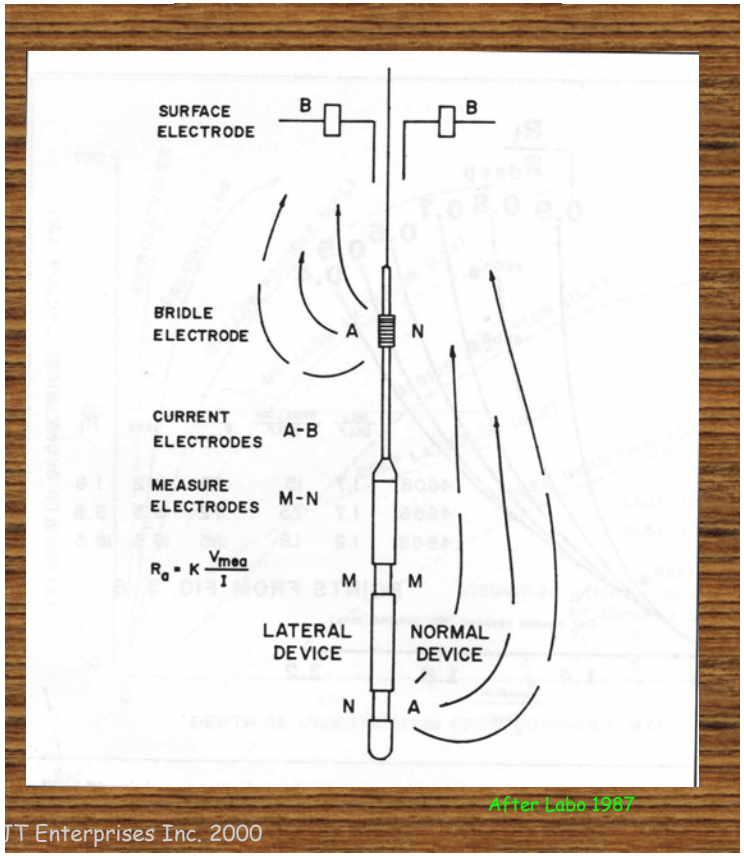
(after van Ditzhuijzen, 1994)

Electric resistivity devices

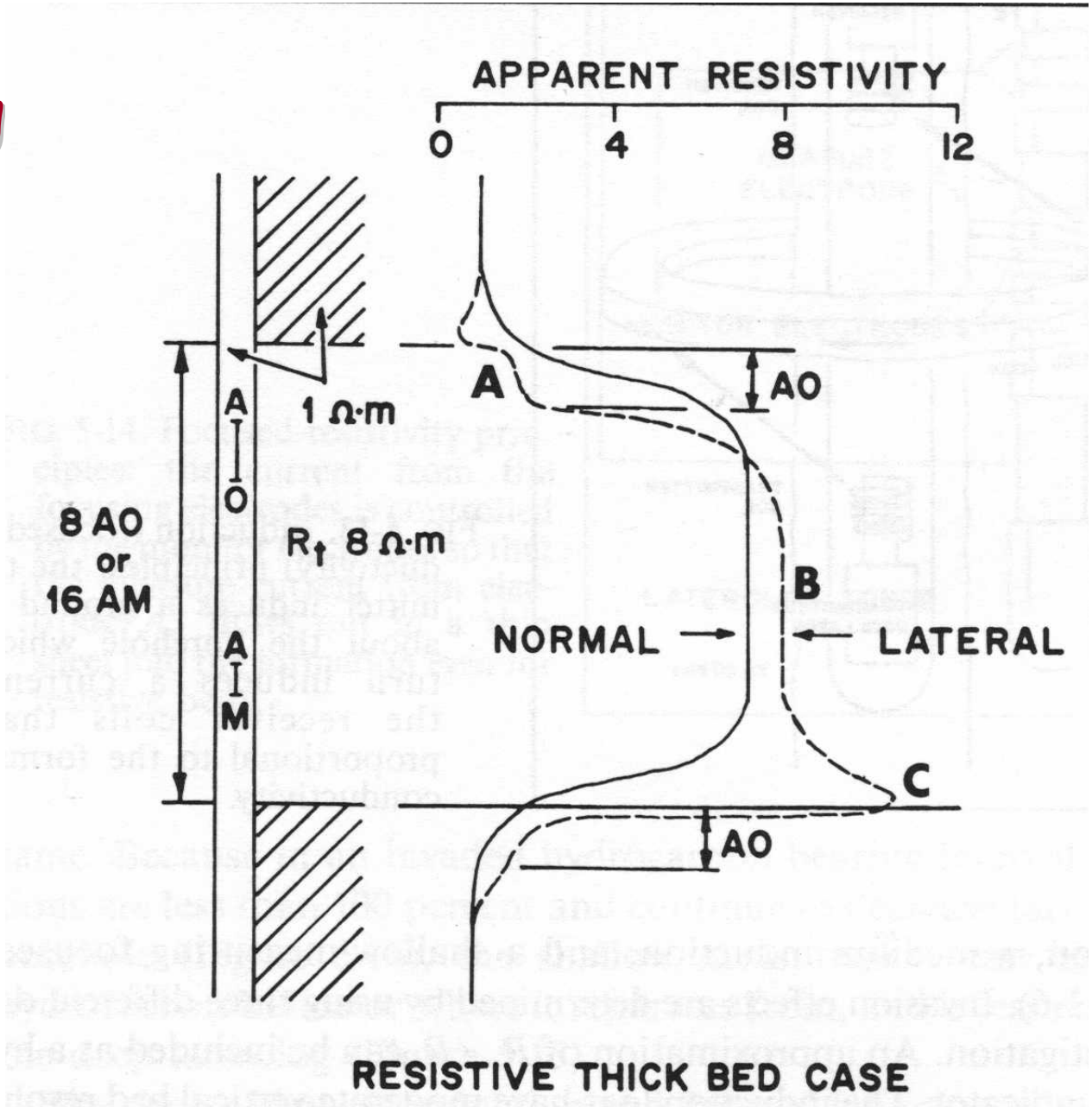
- Normal log
- Lateral log
- LL3
- LL7, DLL
- LL8 – as LL7 but shorter spacing & return
- Rxo logs
- Diplogs

Normal and lateral principle





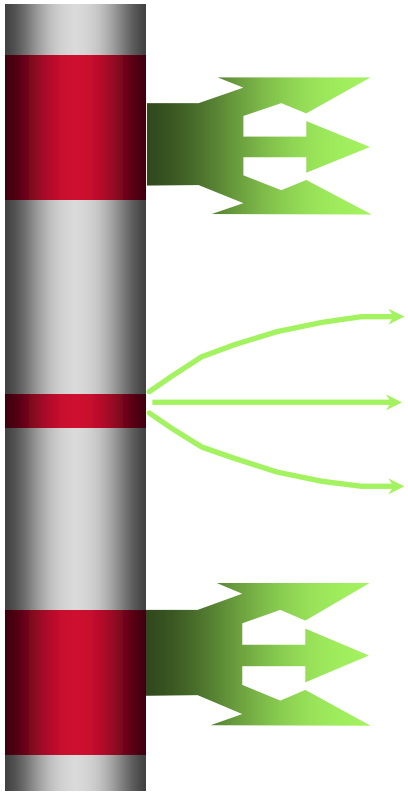
Normal & lateral log curves



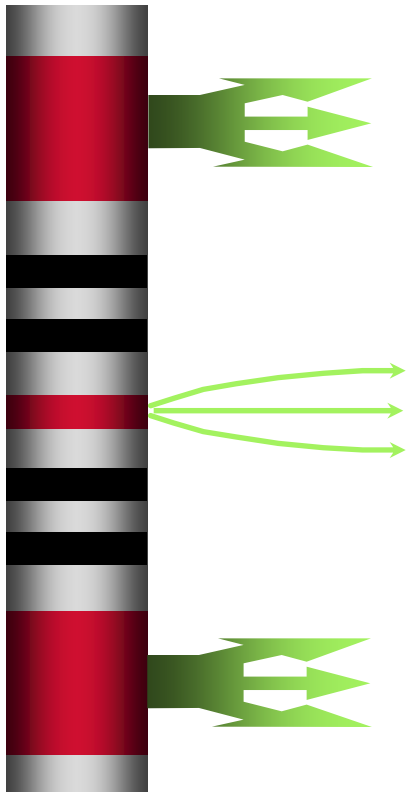
After Labo 1987

LL3 and LL7

LL3

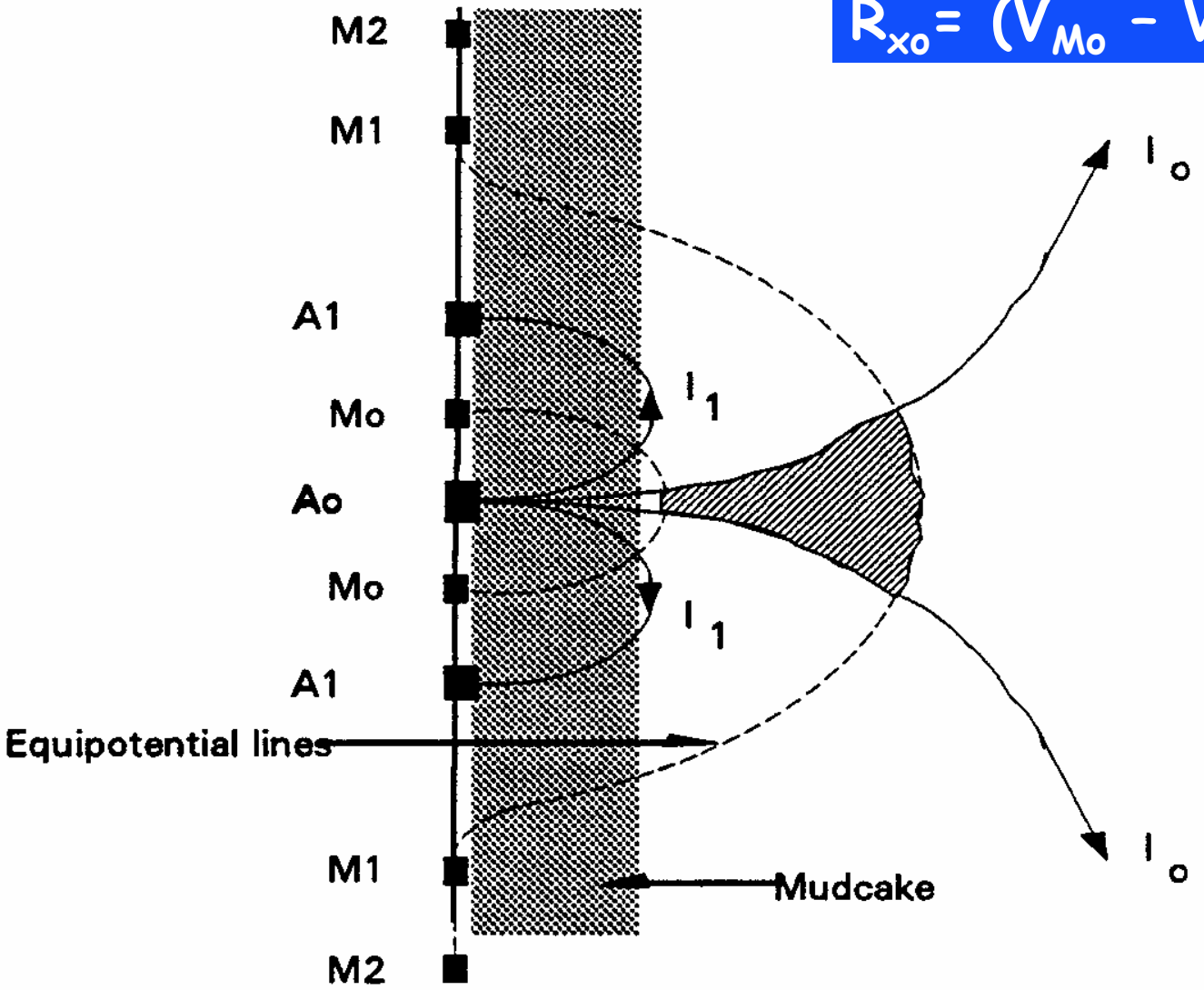


LL7, DLL



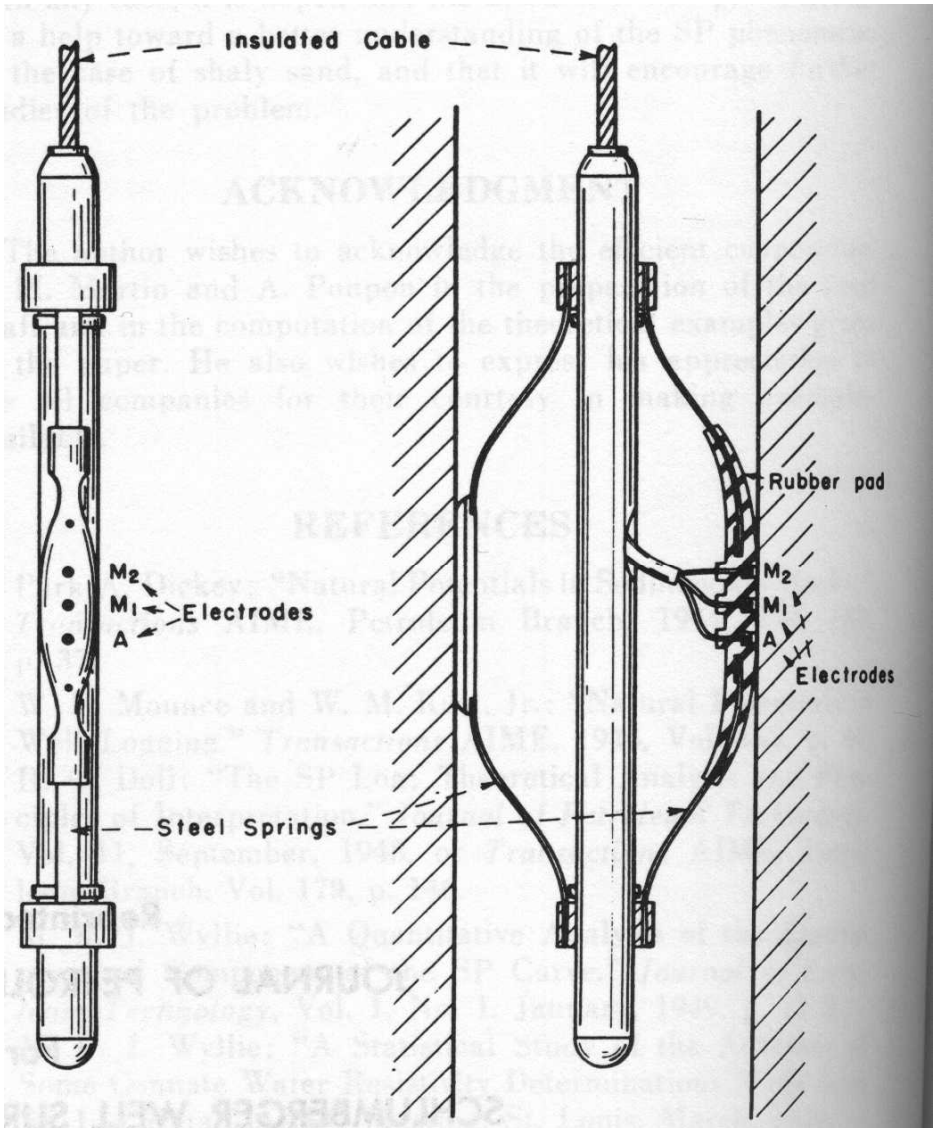
Micro-SFL principle

$$R_{xo} = (V_{Mo} - V_{M1}) / I_o$$

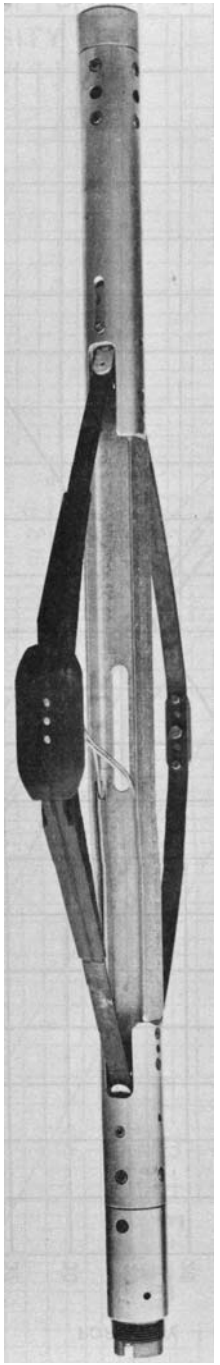


After Peeters, 1995, Schlumberger

Microlog picture



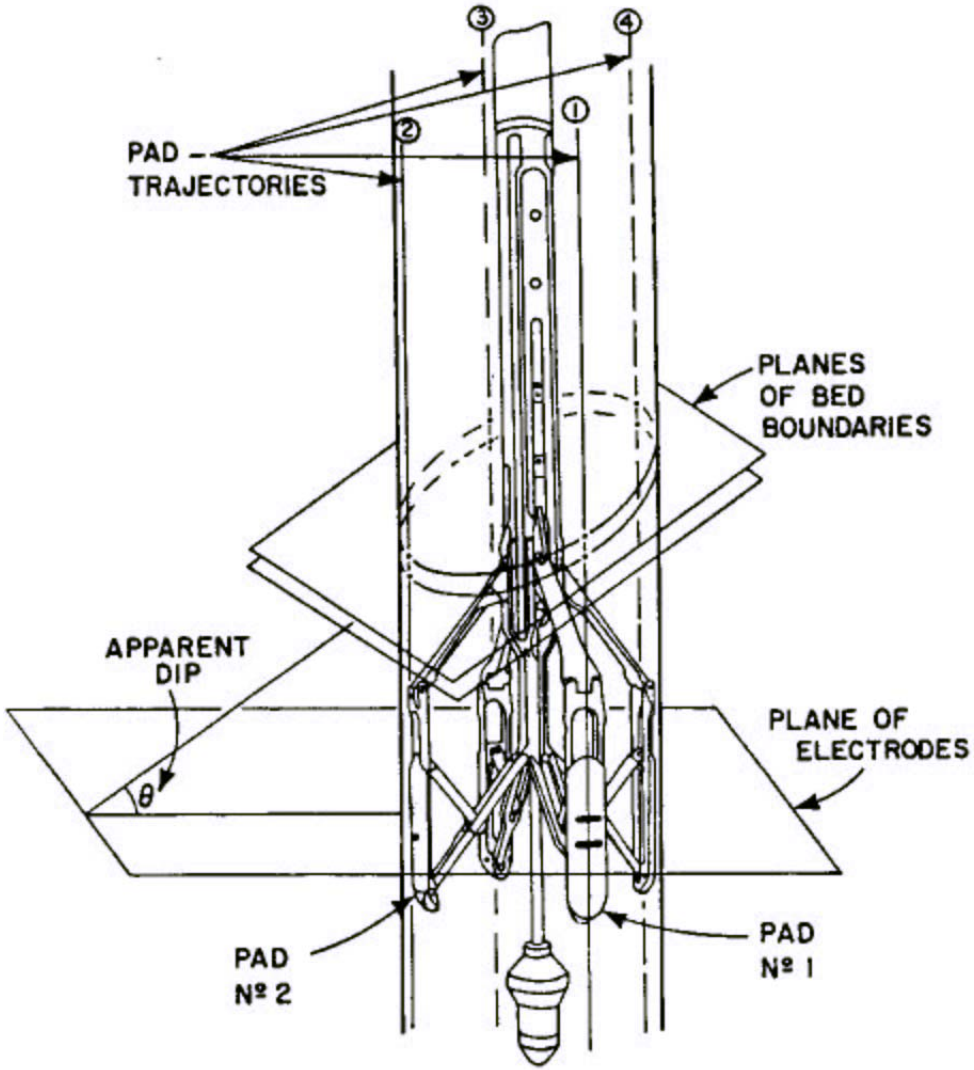
After SPWLA, 1979



Dipmeter tool principle

Different environments

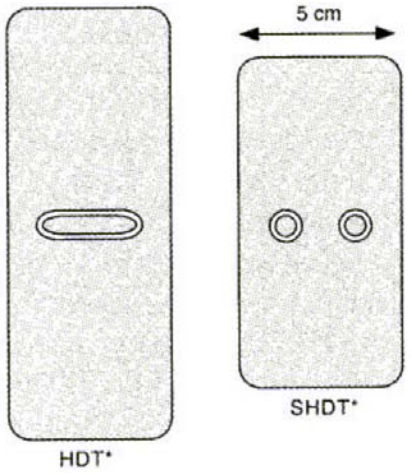
- Water based mud
- Oil based mud

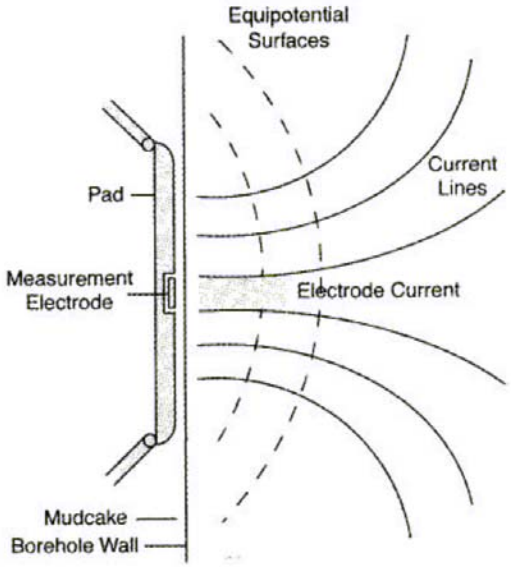


After Luthi, 2001

Diplog principle

- used in water based mud

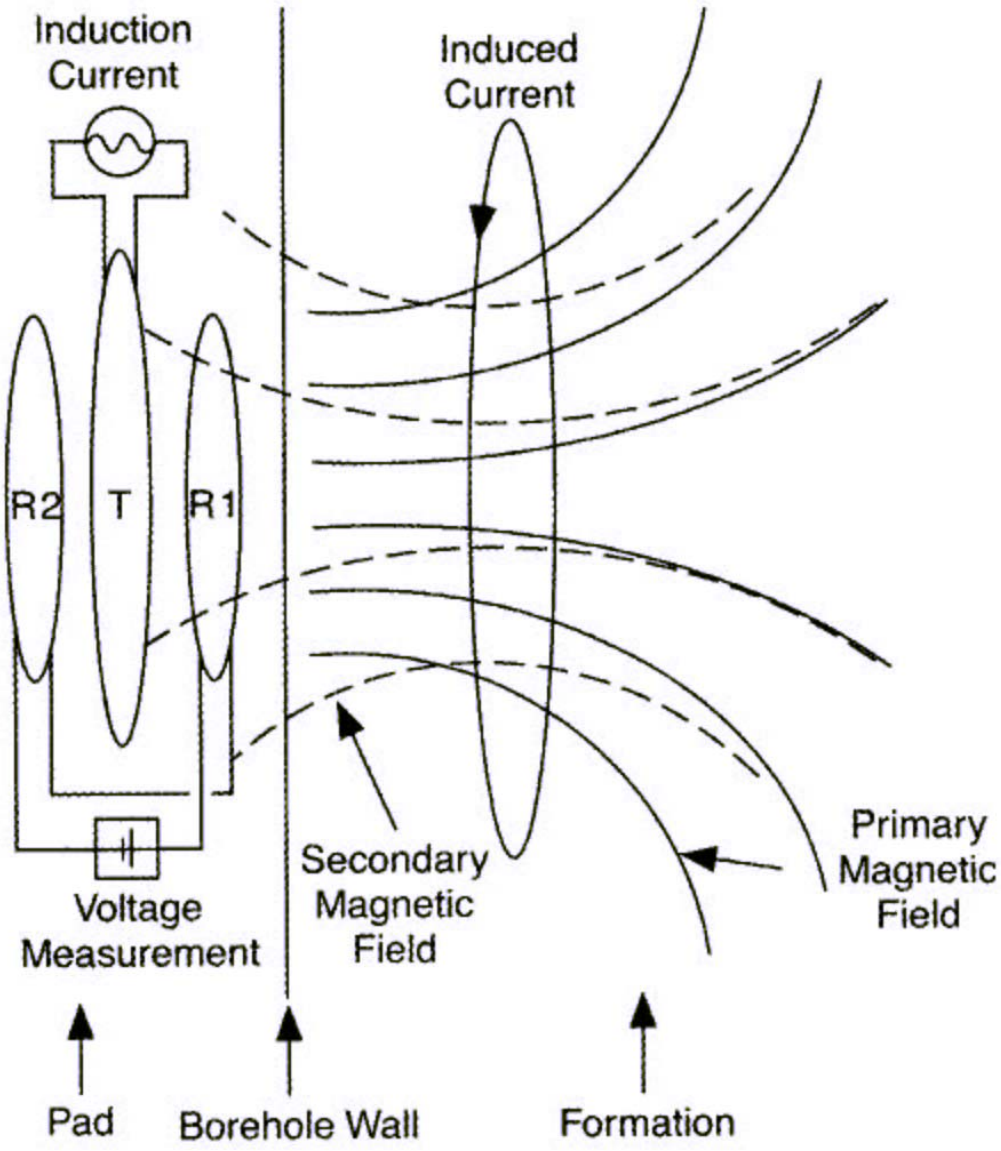




After Luthi, 2001

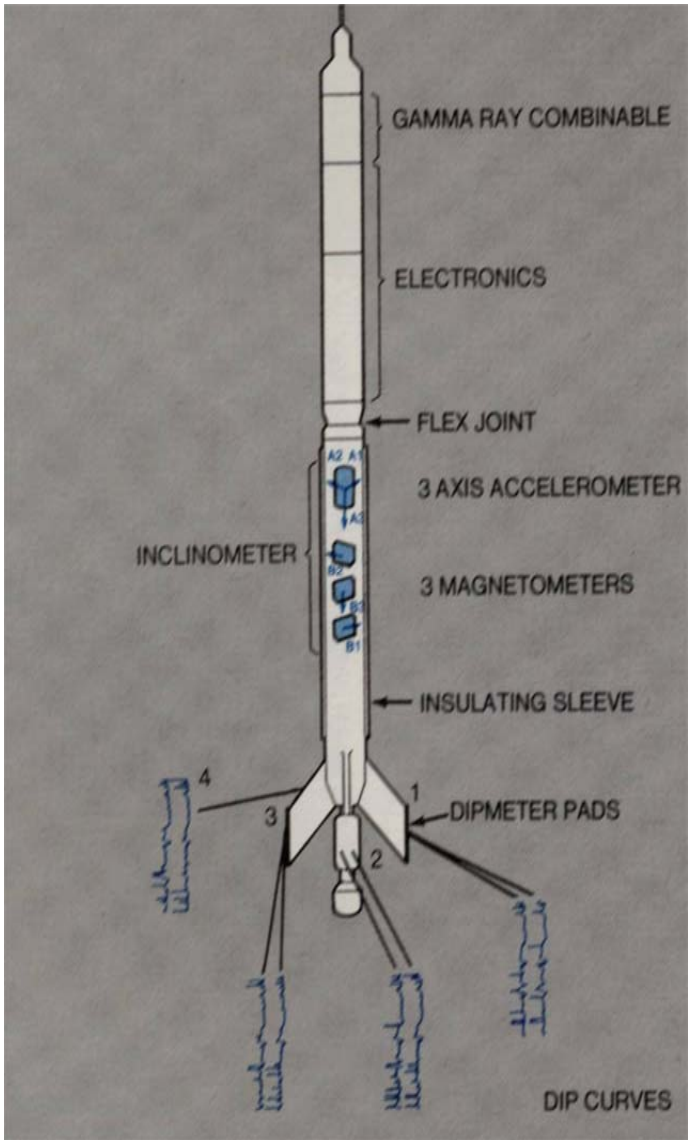
OBM dip tool principle

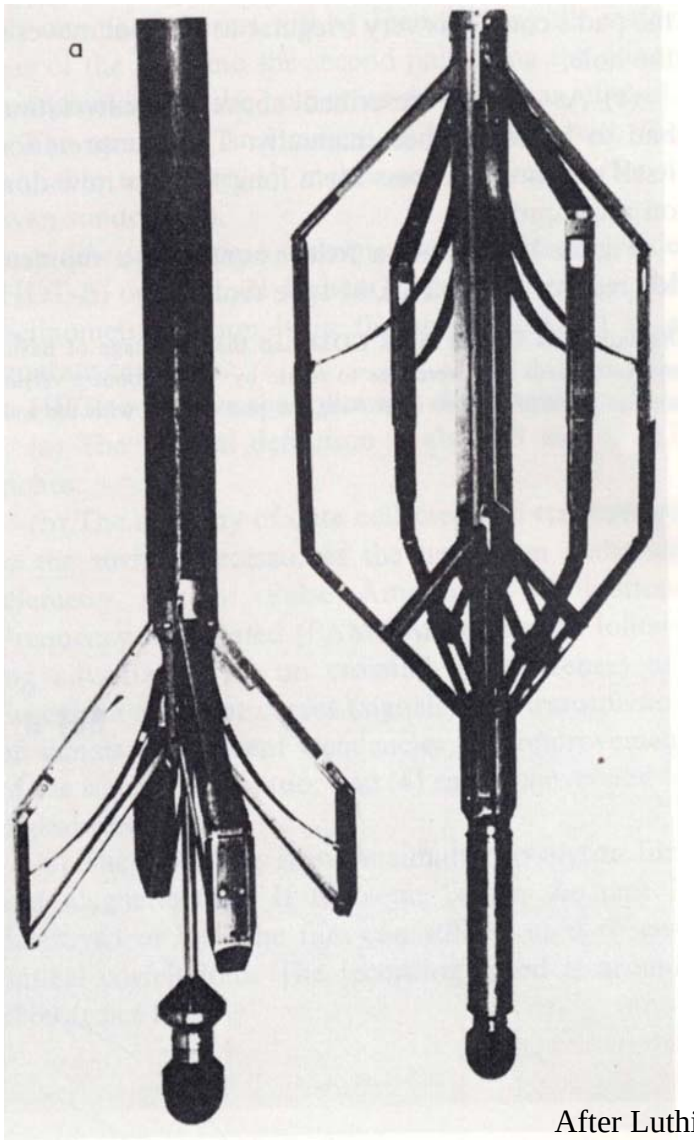
- used in oil based mud



After Luthi, 2001

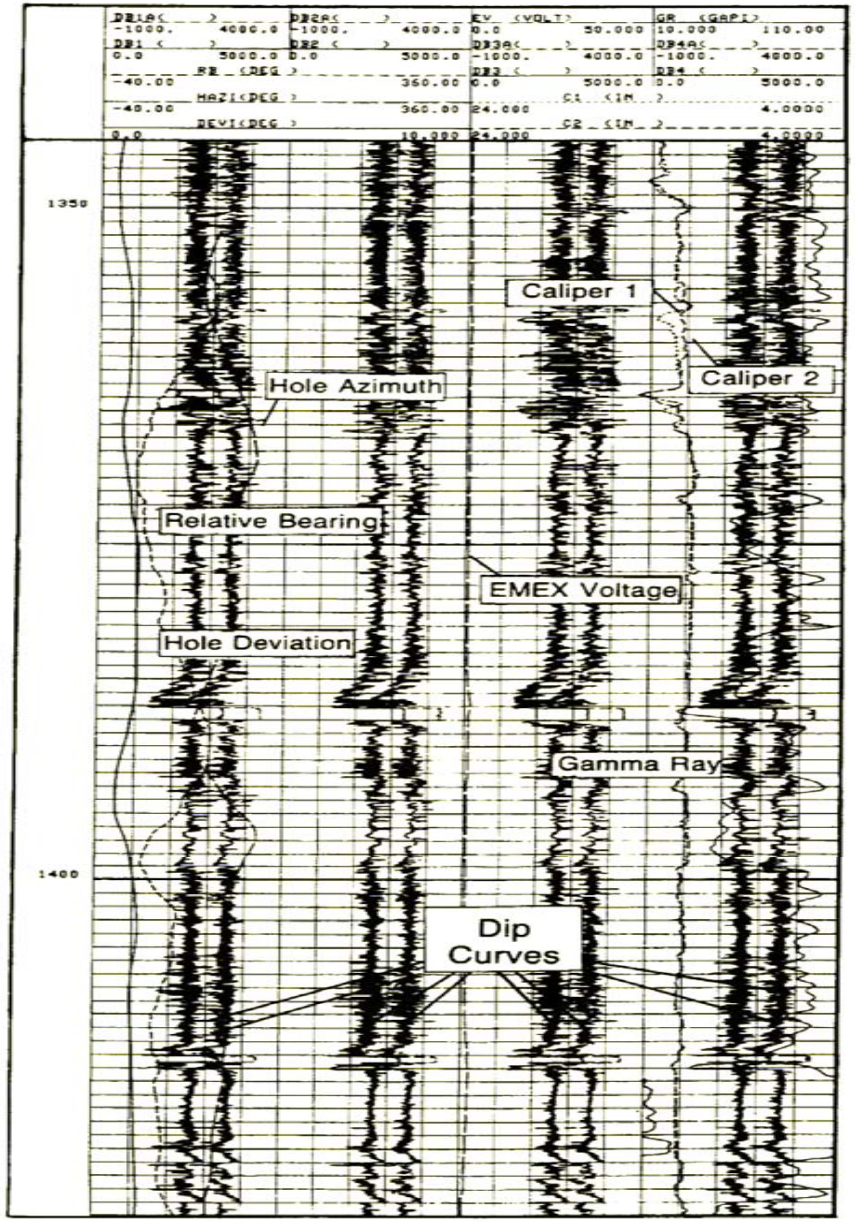
SLB's dip log tool: SHDT





After Luthi, 2001

SHDT™ diplog example



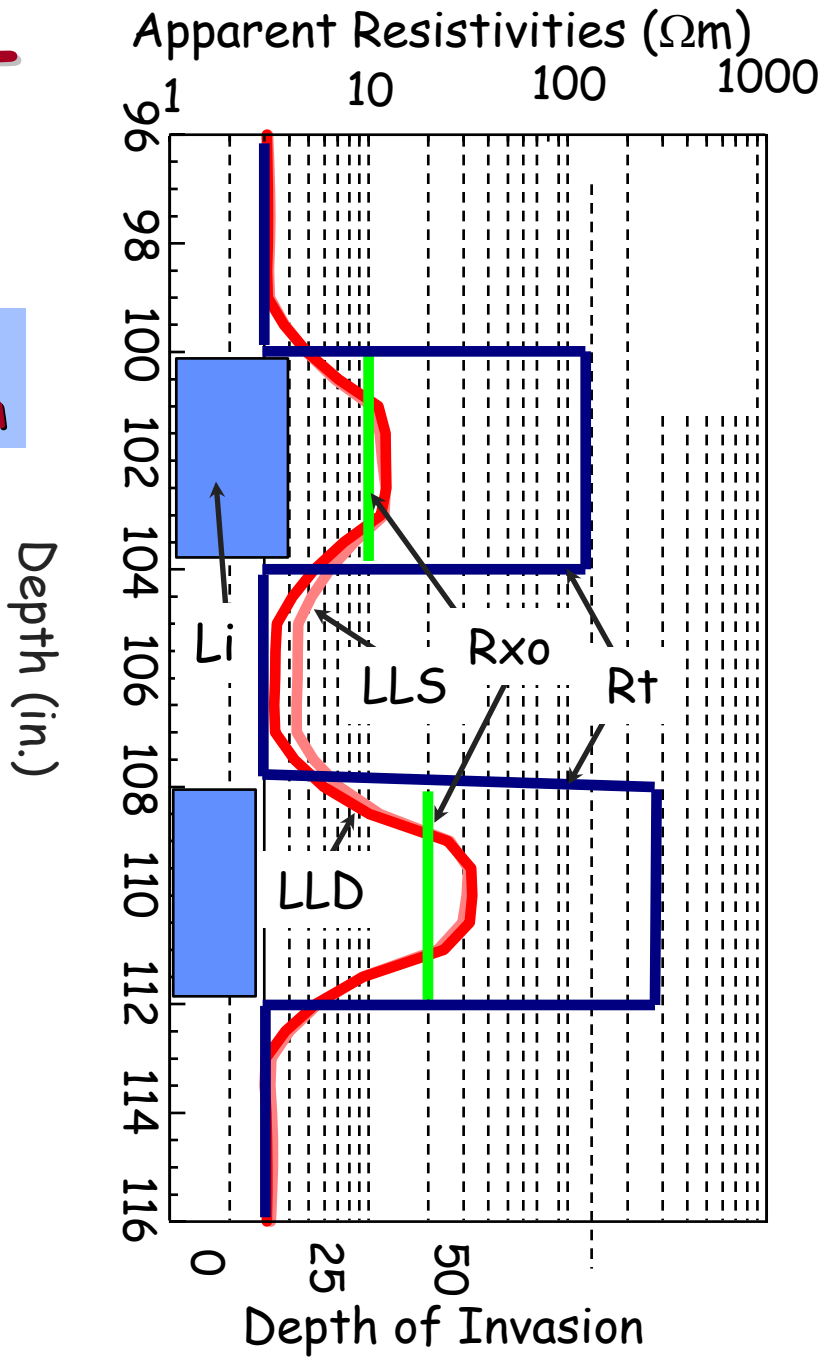
After Luthi, 2001

Resistivity logging: Past, Present & Future

- Introduction
- **Past**
  - History
  - Older tools
  - **Pitfalls**
- Present
  - Overall concept
  - Improved tools
  - Innovative tools
  - Interpretation
- Future

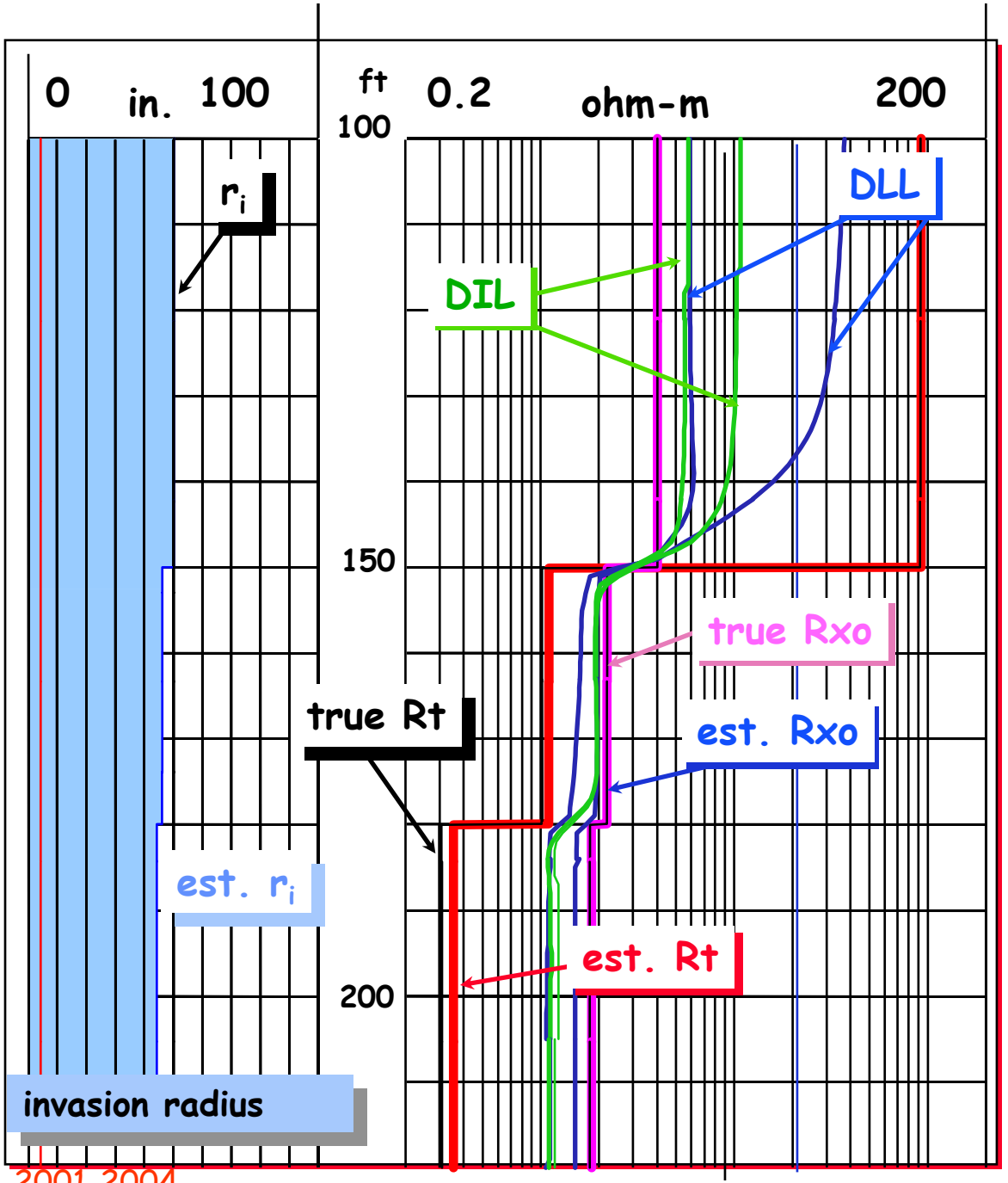
Pitfalls: Laterolog - invaded layers

bhd = 8 in.
Rm = 0.15 W m



After Mezzatesta, 1996

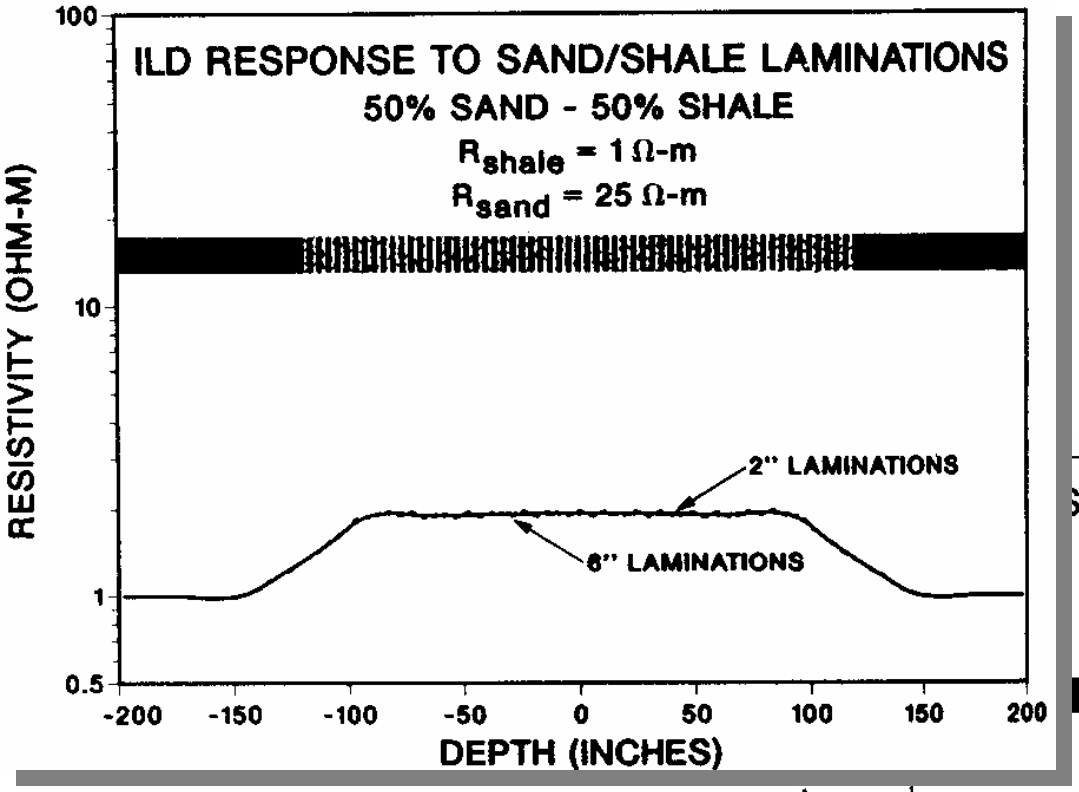
2-D Inversion Results

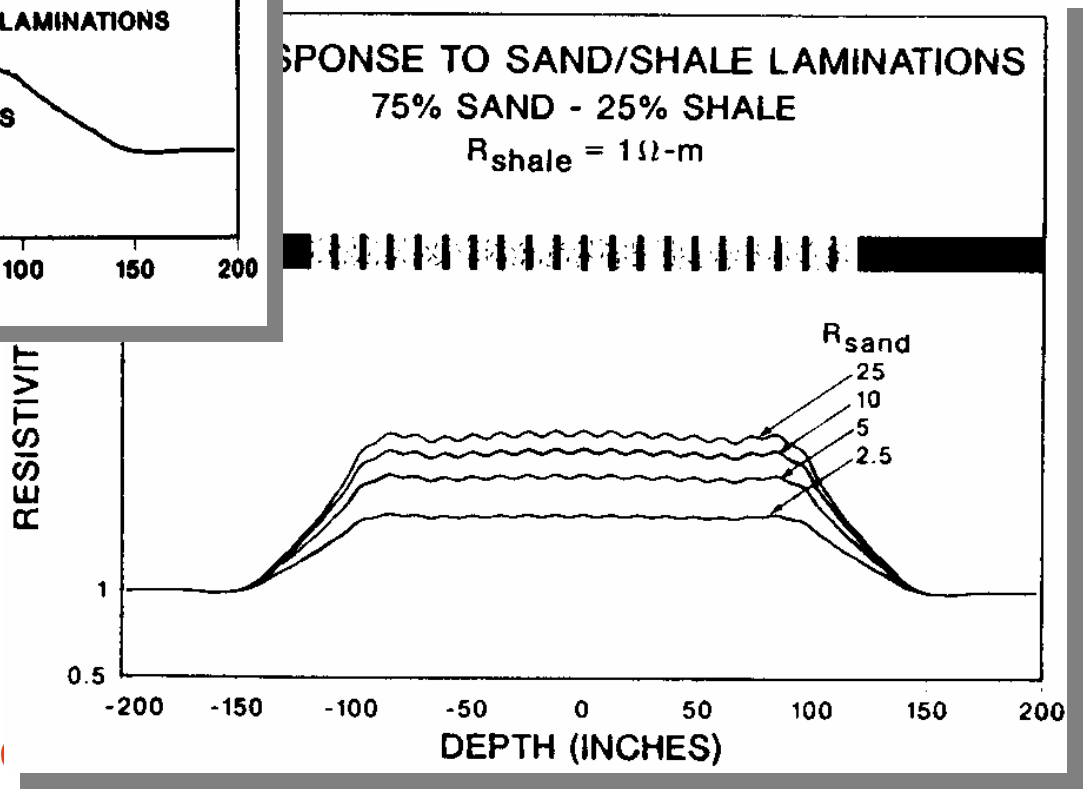


from The Log Analyst, 1994

After Strack et al., 1998

Pitfalls: Induction logs



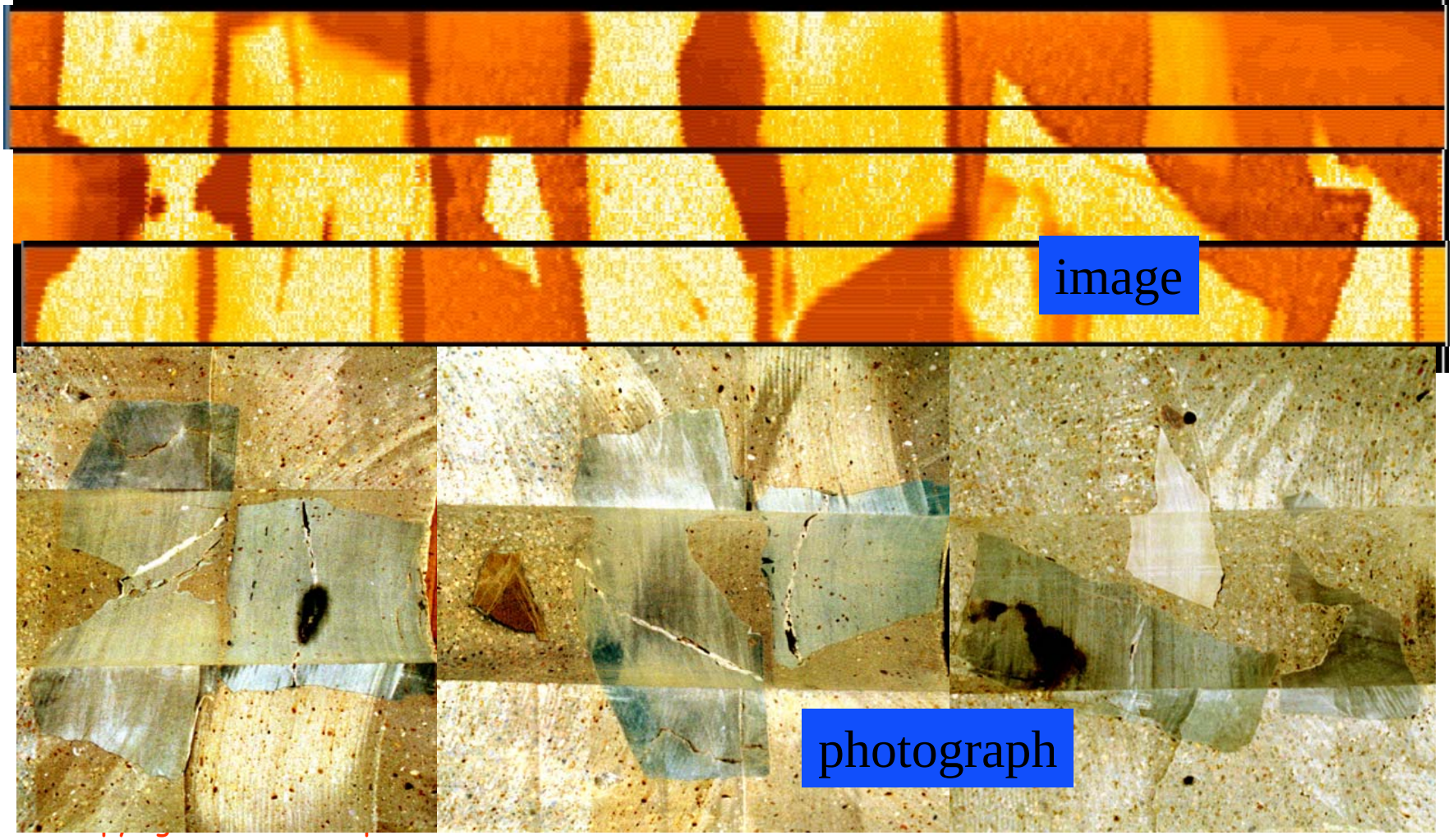


After Anderson, 1986

Resistivity logging: Past, Present & Future

- Introduction
- Past
  - History
  - Older tools
  - Pitfalls
- **Present**
  - **Overall concept**
    - **→ Direct image of geology**
    - **→ More data**
    - **→ New measurements**
    - **→ Better understanding of measurements & geology**
  - Improved tools
  - Innovative tools
  - Interpretation
- Future

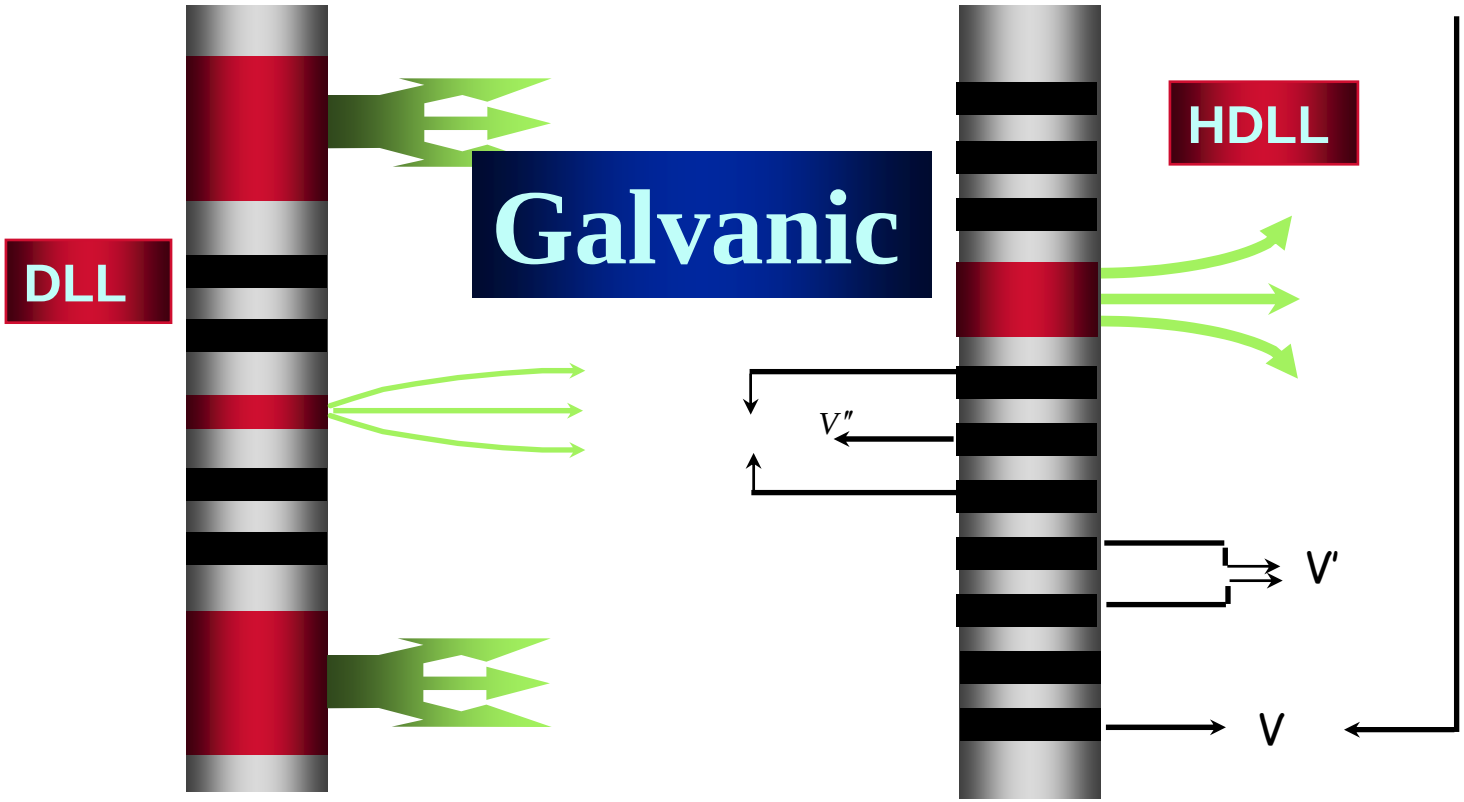
Combined photo & image



From meters to acquisition systems

Limits

Possibilities

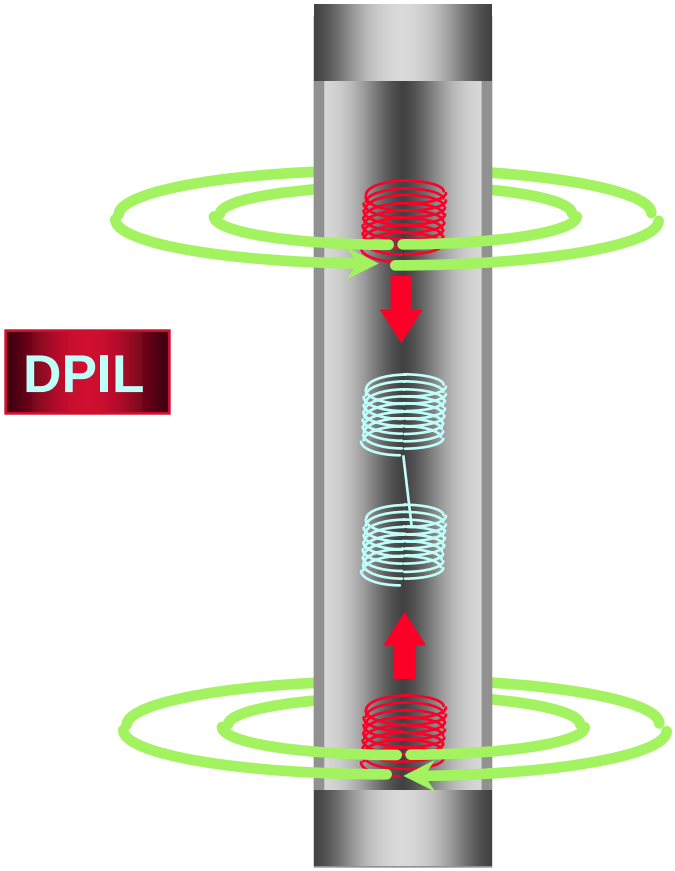


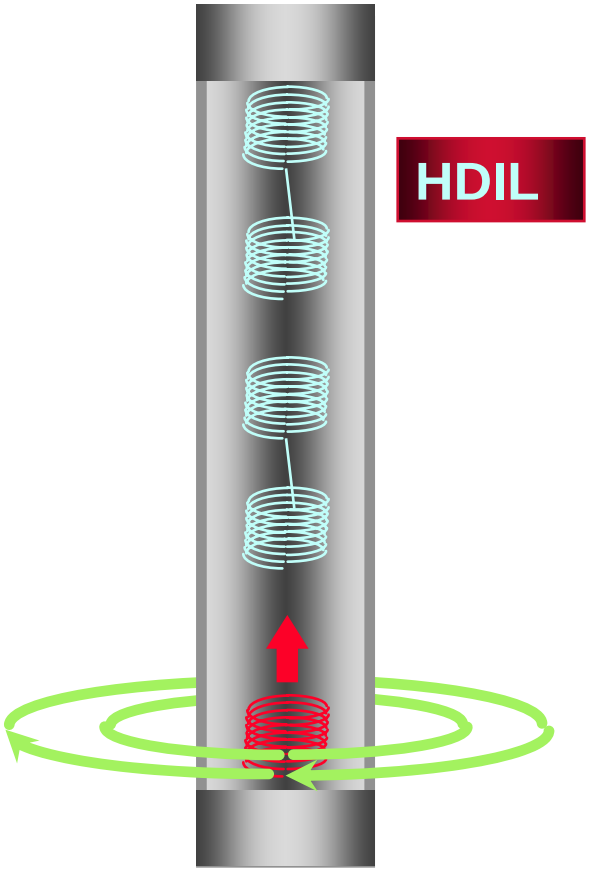
Apparent Rt

Data ⟶ Inversion ⟶ Rt

After Strack, 1999

From meters to acquisition systems





Apparent Rt

Raw Array → Data Inversion → Rt

After Strack et al., 1998

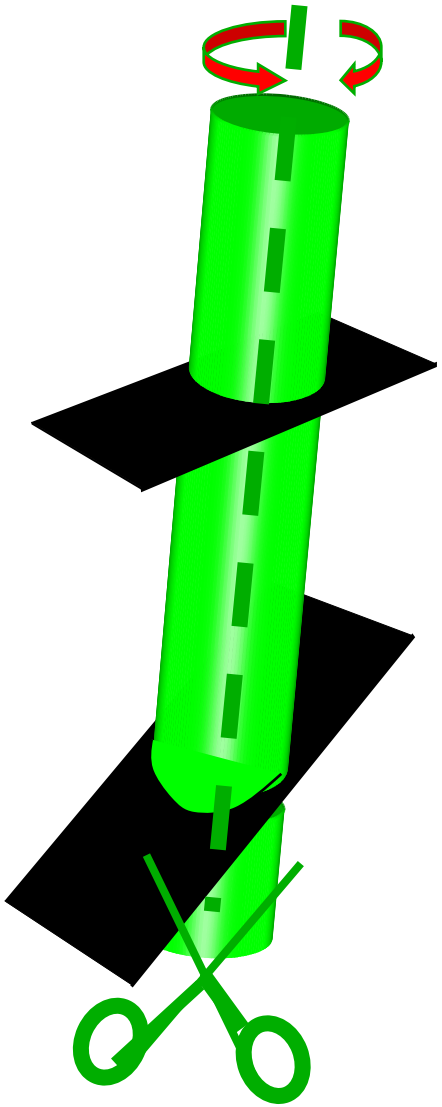
Resistivity logging: Past, Present & Future

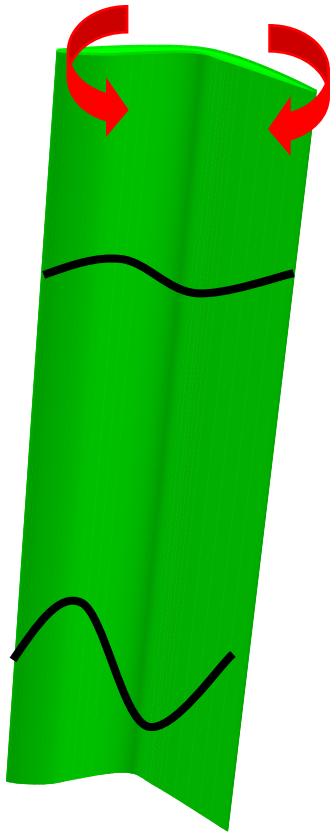
- Introduction
- Past
  - History
  - Older tools
  - Pitfalls
- **Present**
  - Overall concept
  - **Improved tools**
    - **➔Image tools (WBM & OBM)**
    - **➔Array tools (Induction & Laterologs)**
  - Innovative tools
  - Interpretation
- Future

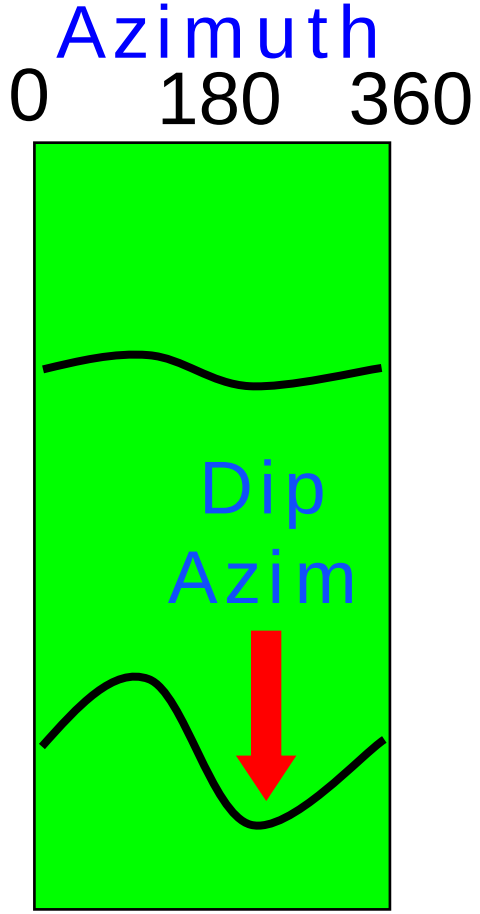
From diplog to imaging

- Imaging started with dip logs
- Today multi button imagers replace most dip logs
- Image tool are used for geologic interpretation
- Could be used also for reserve estimates

How the display is derived

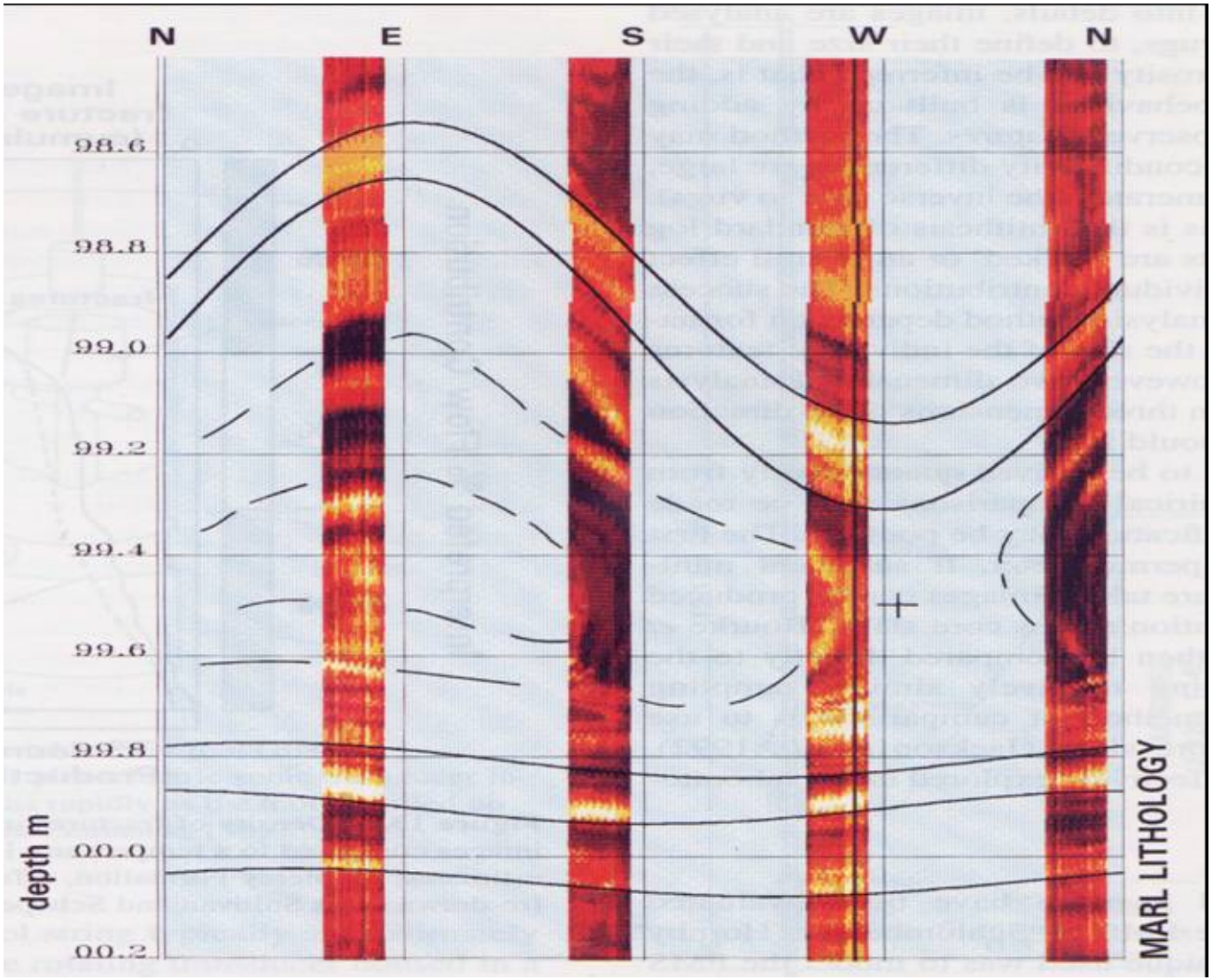






Courtesy of Paauwe, 2001

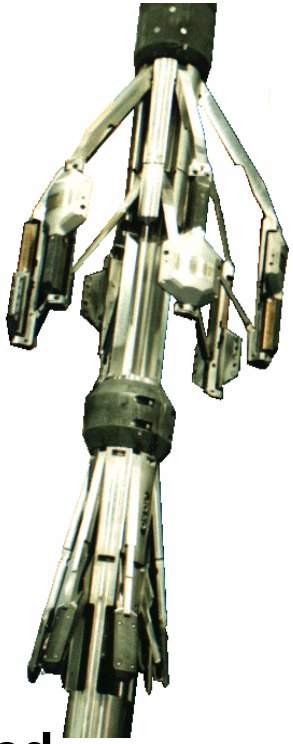
Example



After Rider, 1996

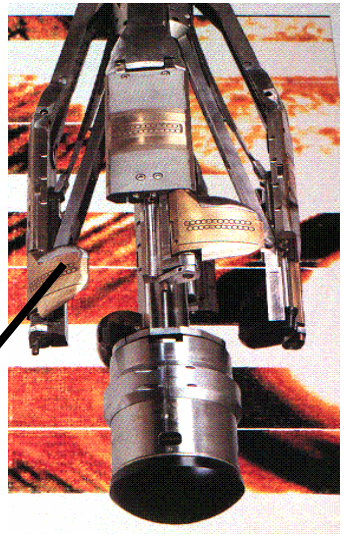
Current electrical imagers

6 alternately offset electrical imaging pads



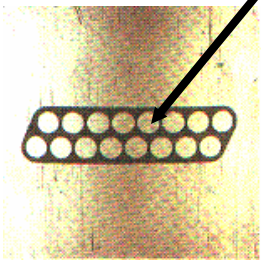
Schlumberger

FMI



Powered standoff centralizes tool

CBIL is attached to lower end of tool string

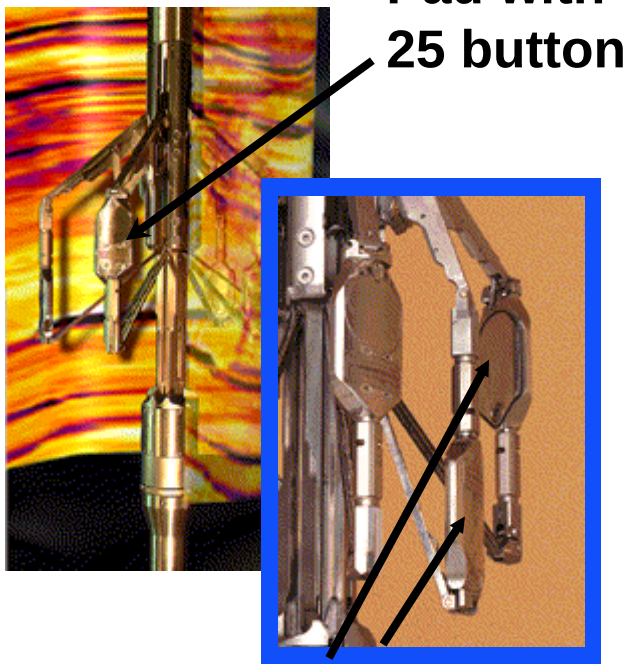


WESTERN ATLAS

STAR

EMI

Pad with 25 buttons

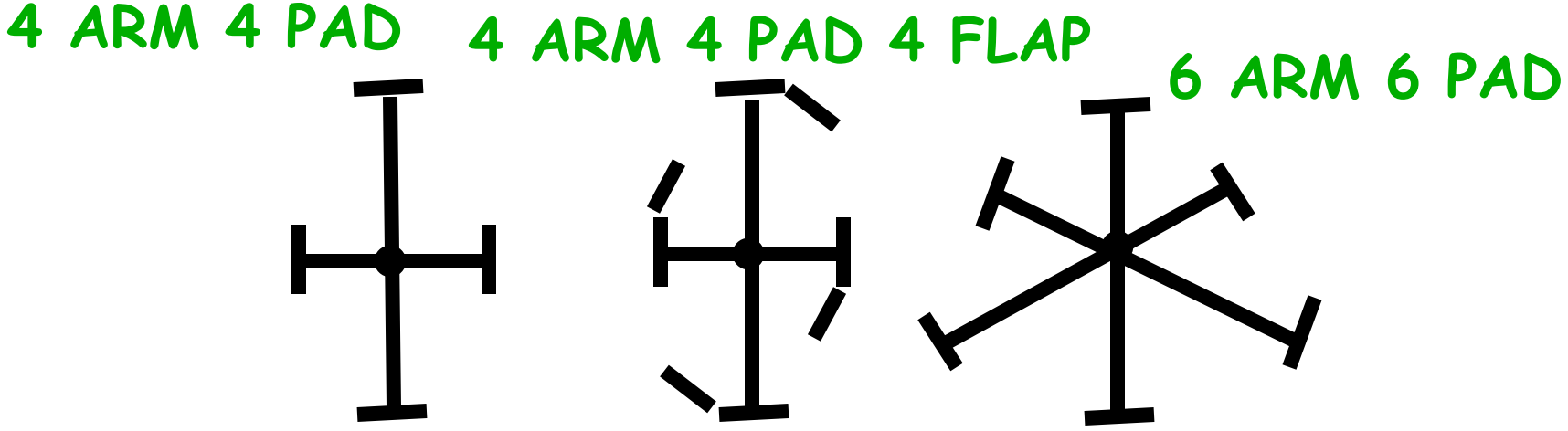


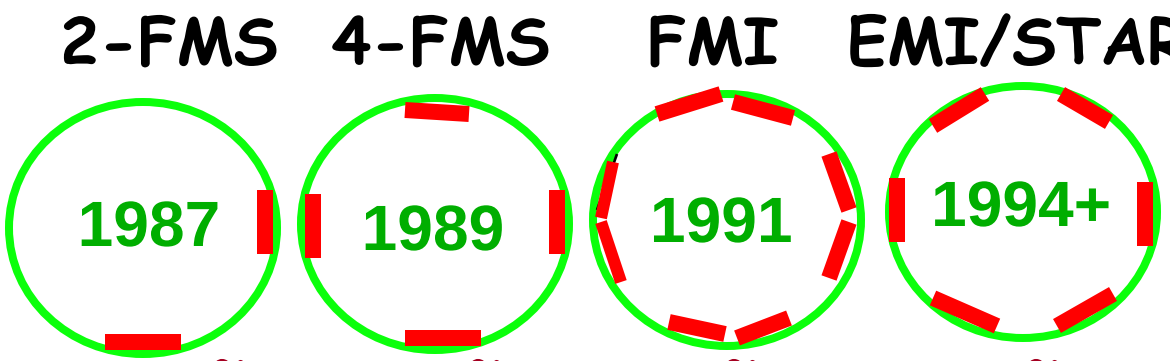
Alternate pads offset from each other

HALLIBURTON

Courtesy of Paauwe, 2001

RESISTIVITY IMAGE COVERAGE





	2-FMS	4-FMS	FMI	EMI/STAR
8.5" hole:	20%	40%	80%	60%
12.25" hole:	14%	28%	56%	42%

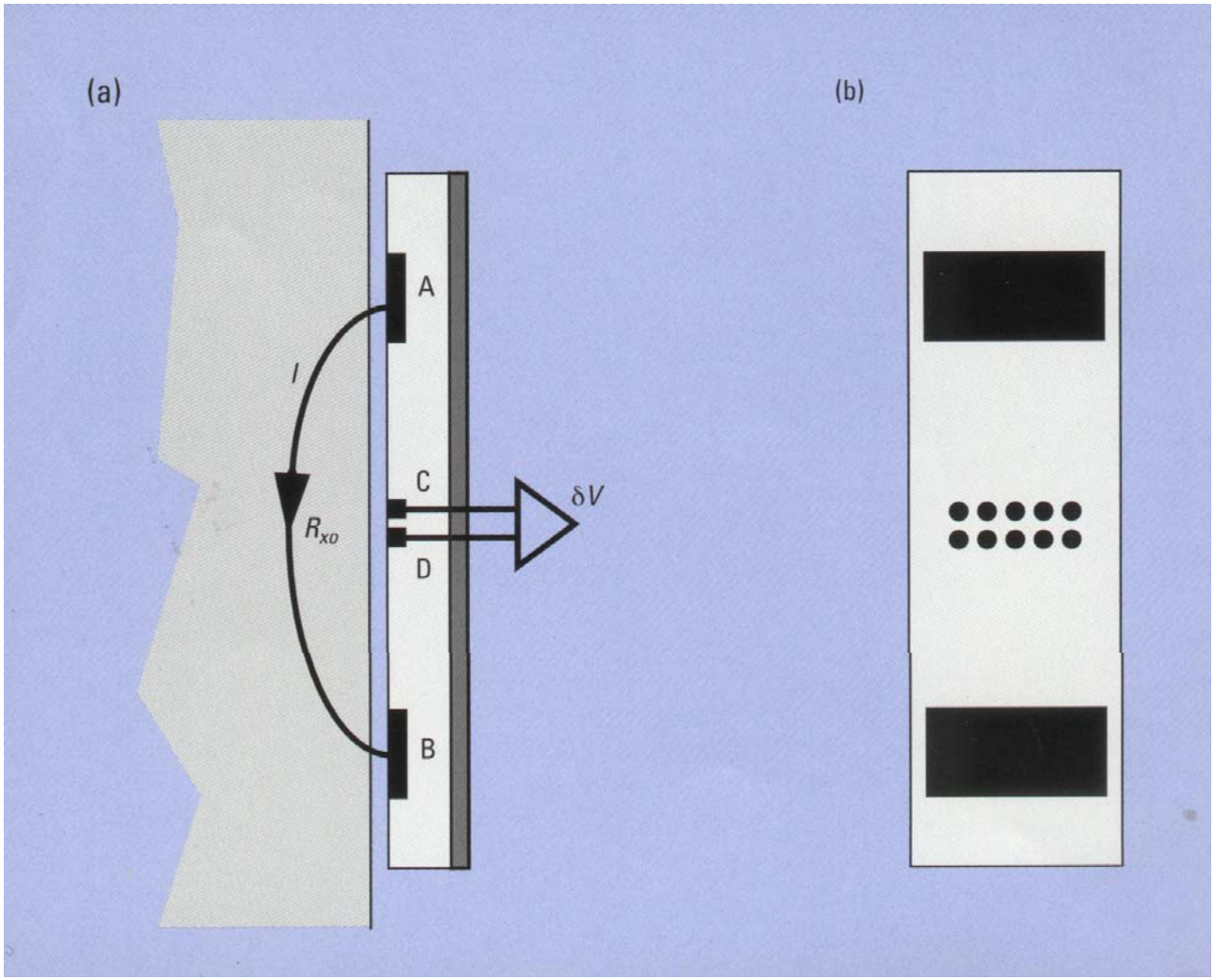
Courtesy of Paauwe, 2001

Oil based mud (OBM) imager

- Difficult to get current via OBM
- Resolution must be on formation scale
- Resistivity range must be large
- Imager must have higher lateral/vertical res.
- OBMI™ introduced 2001
- Cheung et al., 2001 paper

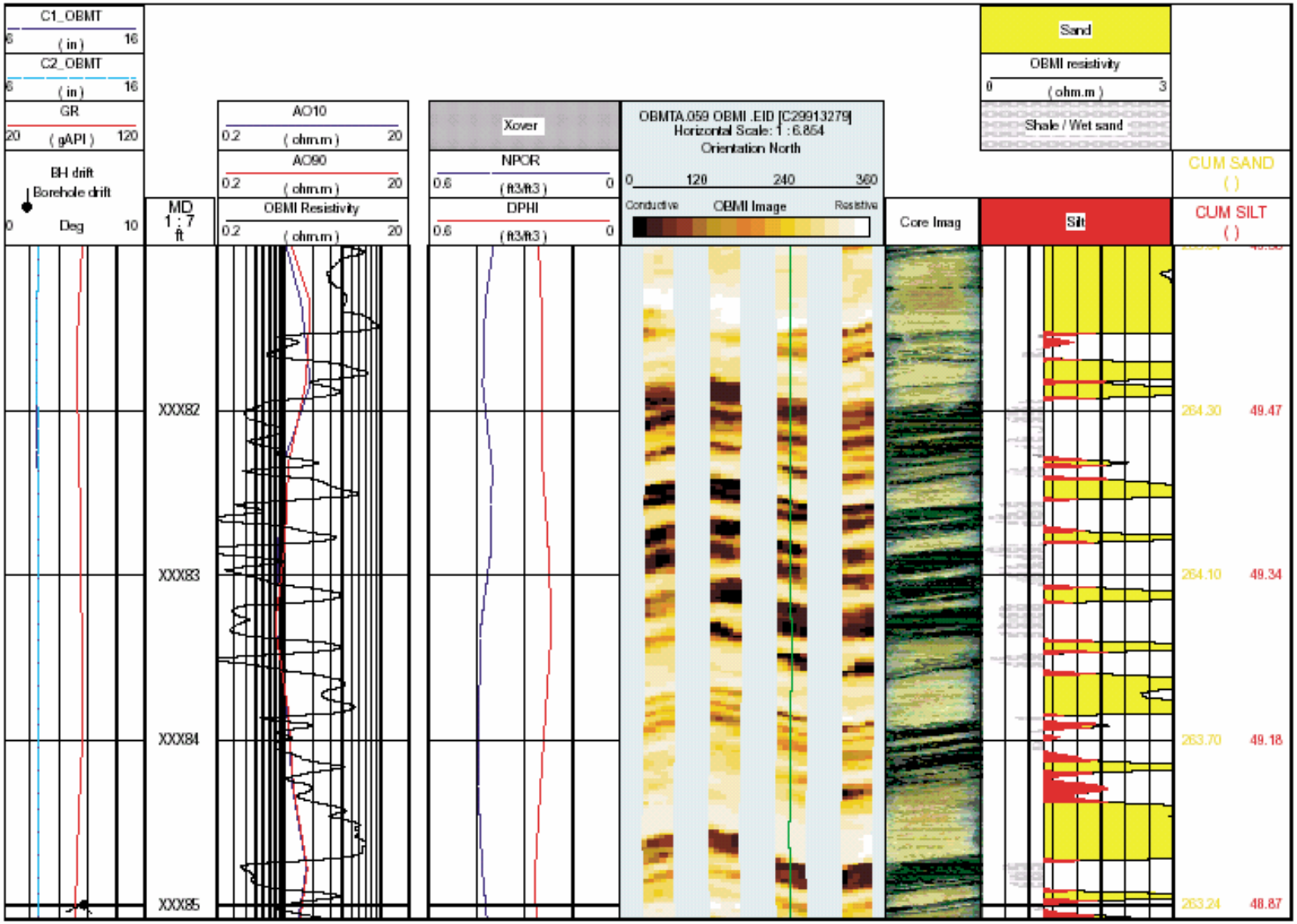
OBMI trademark of Schlumberger

OBMI™ functional diagram



(Schlumberger OBMI,2002)

OBMI™ versus core image

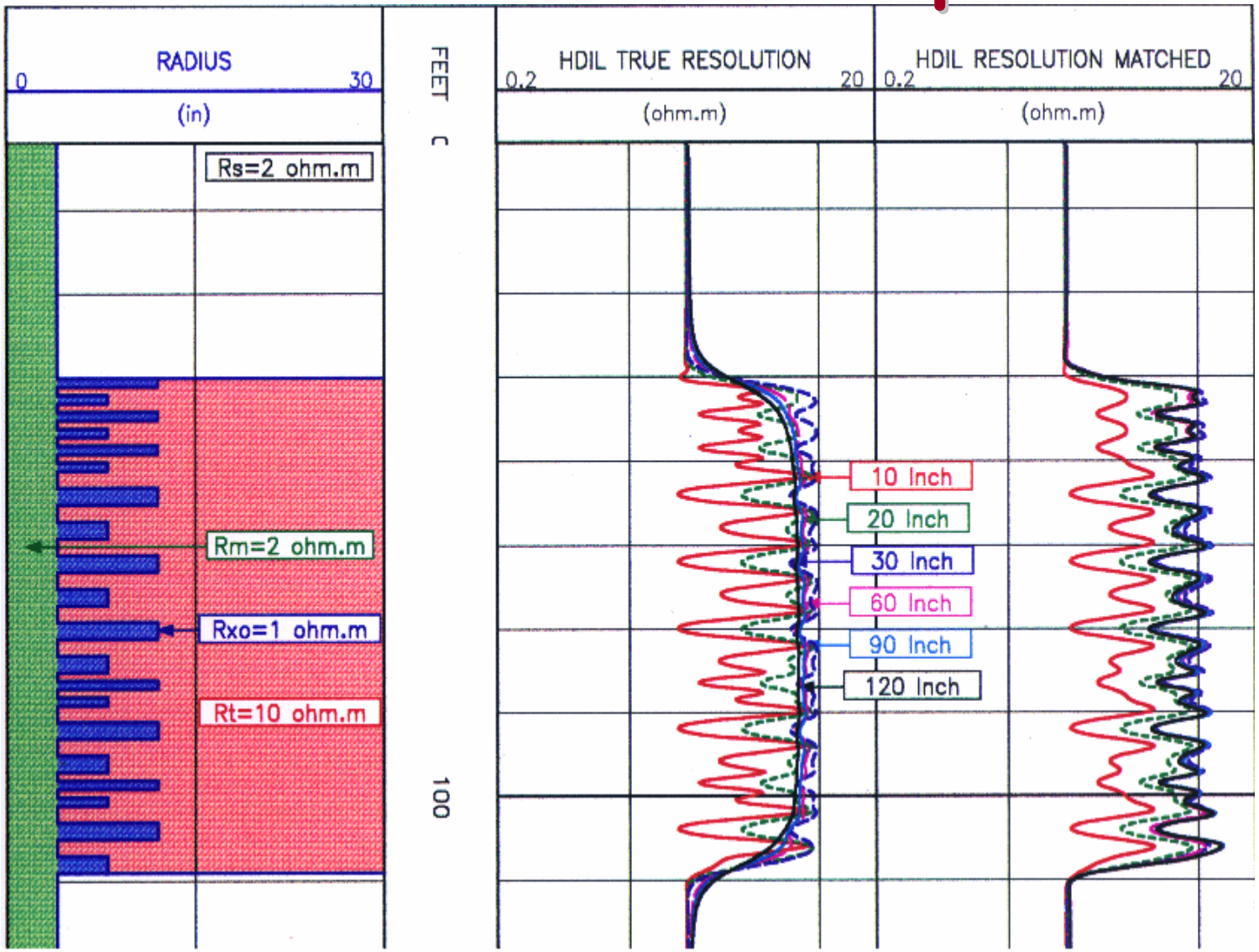


After Cheung et al., 2001

Array industion requirements

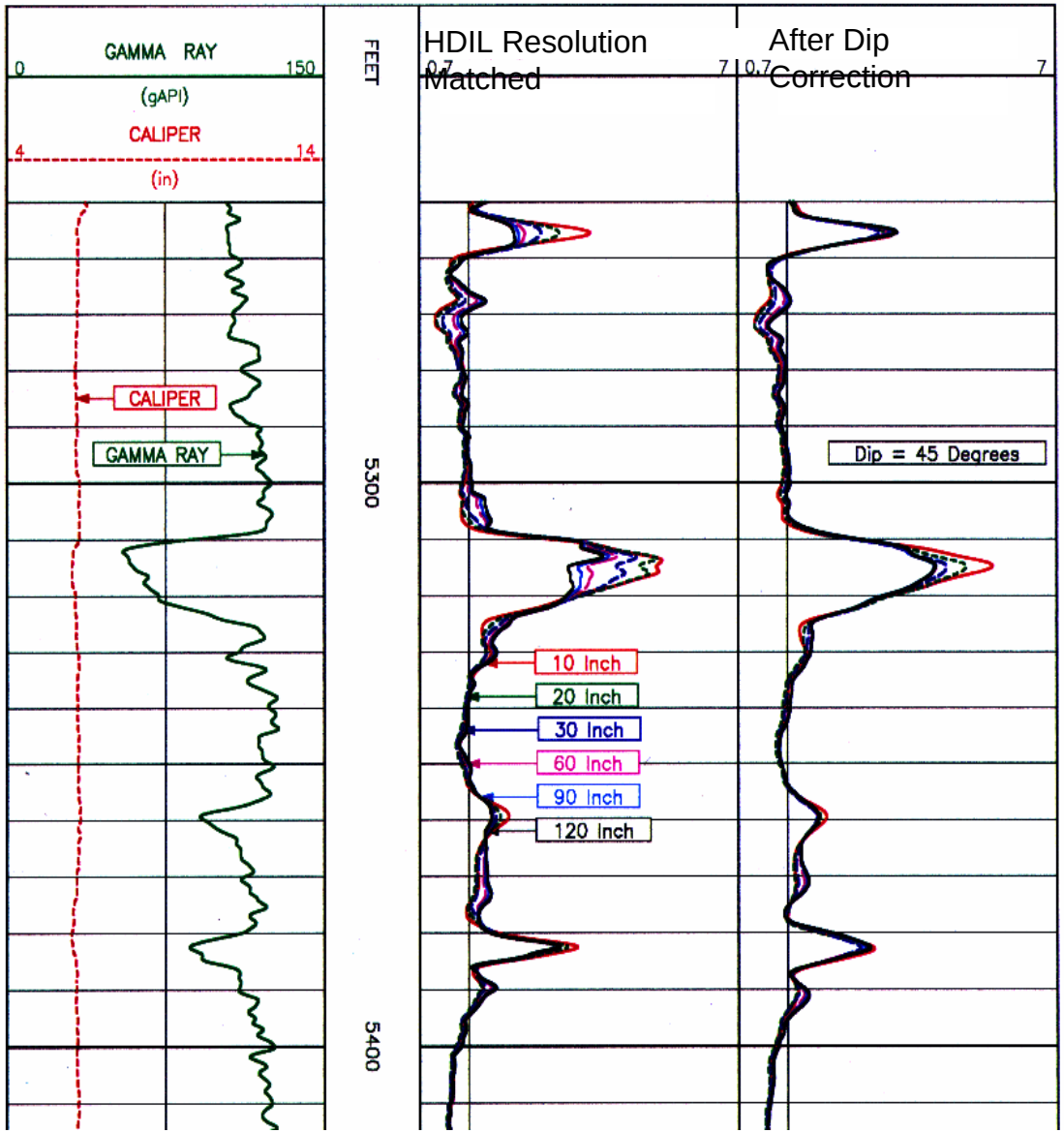
- Multiple depths of investigation
- Multiple vertical resolution (improved!)
- Increased depth of investigation
- More reliable measurements
- Streamlined interpretation

Resolution matched example



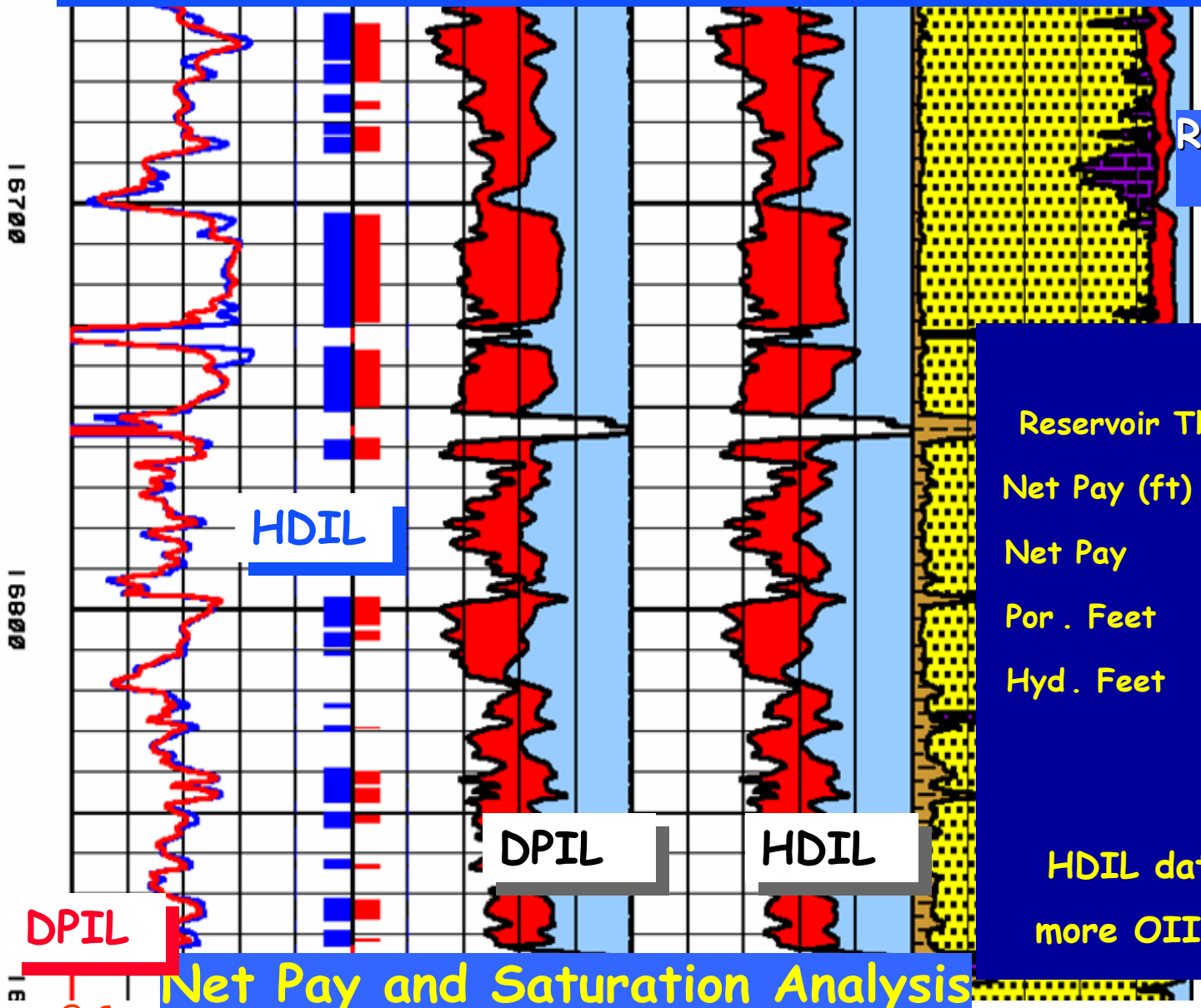
After Beard et al., 1996

Array Induction: Dip Effect & Correction



After Beard and Evans, 1996

Step change through hardware



Reserves estimate
DPIL vs. HDIL

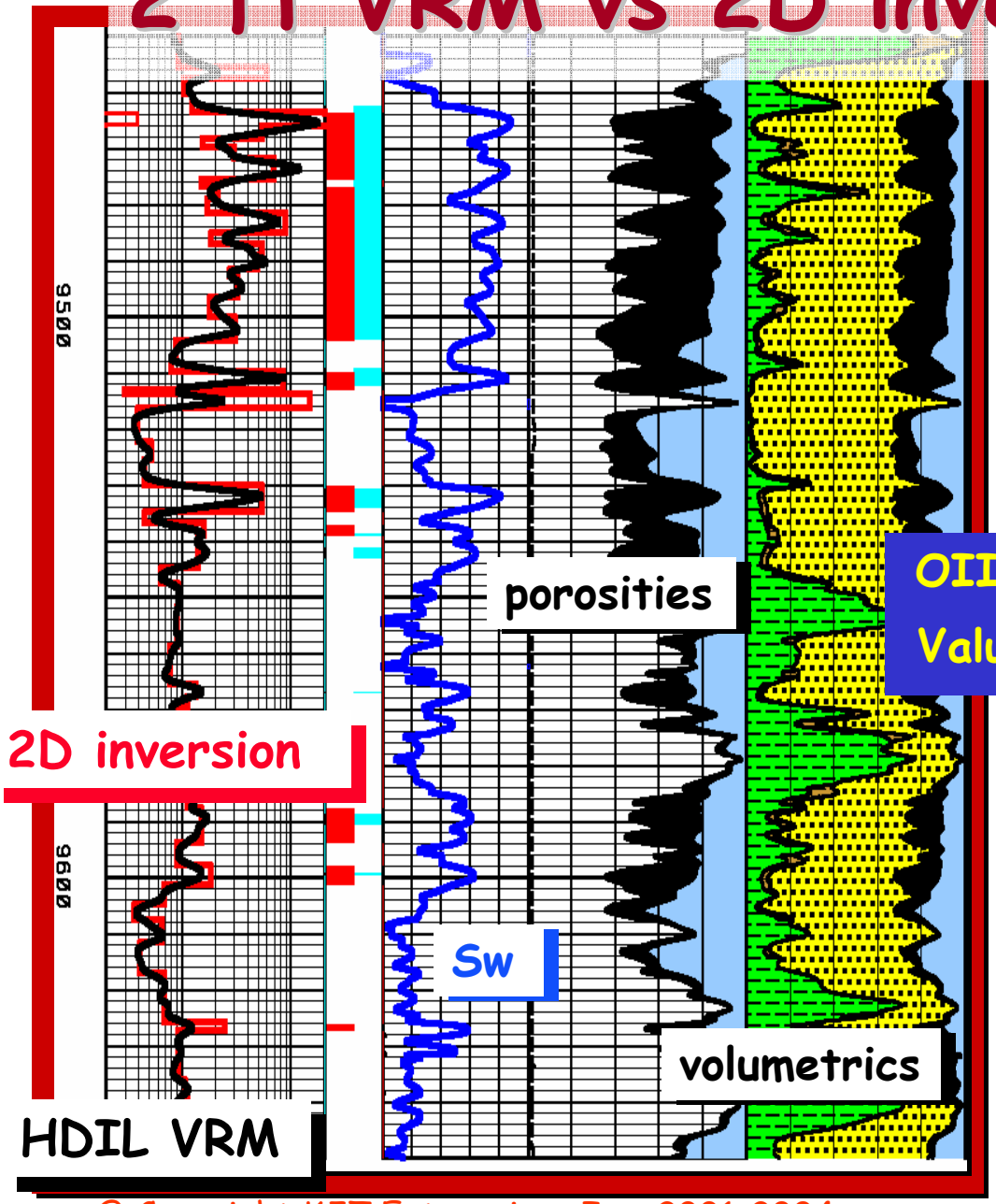
	DPIL	HDIL
Reservoir Thickness:		270 ft
Net Pay (ft)	103.6	130.1
Net Pay	38.4%	48.2%
Por . Feet	15.4 ft	18.9 ft
Hyd . Feet	7.4 ft	9.2 ft

HDIL data allowed 24%
more OIIP be booked.

Net Pay and Saturation Analysis

After Strack et al., 1998

2 ft VRM vs 2D inversion



$$OIIP = (A*h)*Por*(1-Sw)$$

A= 160 acre

Assume 7,758 API Bbl/acre-foot

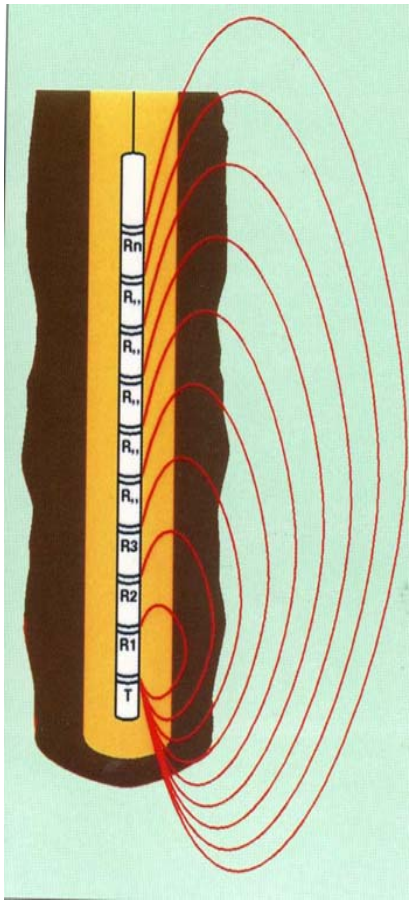
1 Bbl = $22

	2 ft VRM Curves	2D Inversion
OIIP	14,912,427 Bbl	16,173,193 Bbl
Value	328 M$	356 M$
h	67.00 ft	74.75 ft
Por	25.8%	25.9%
(1-Sw)	69.5%	67.3%

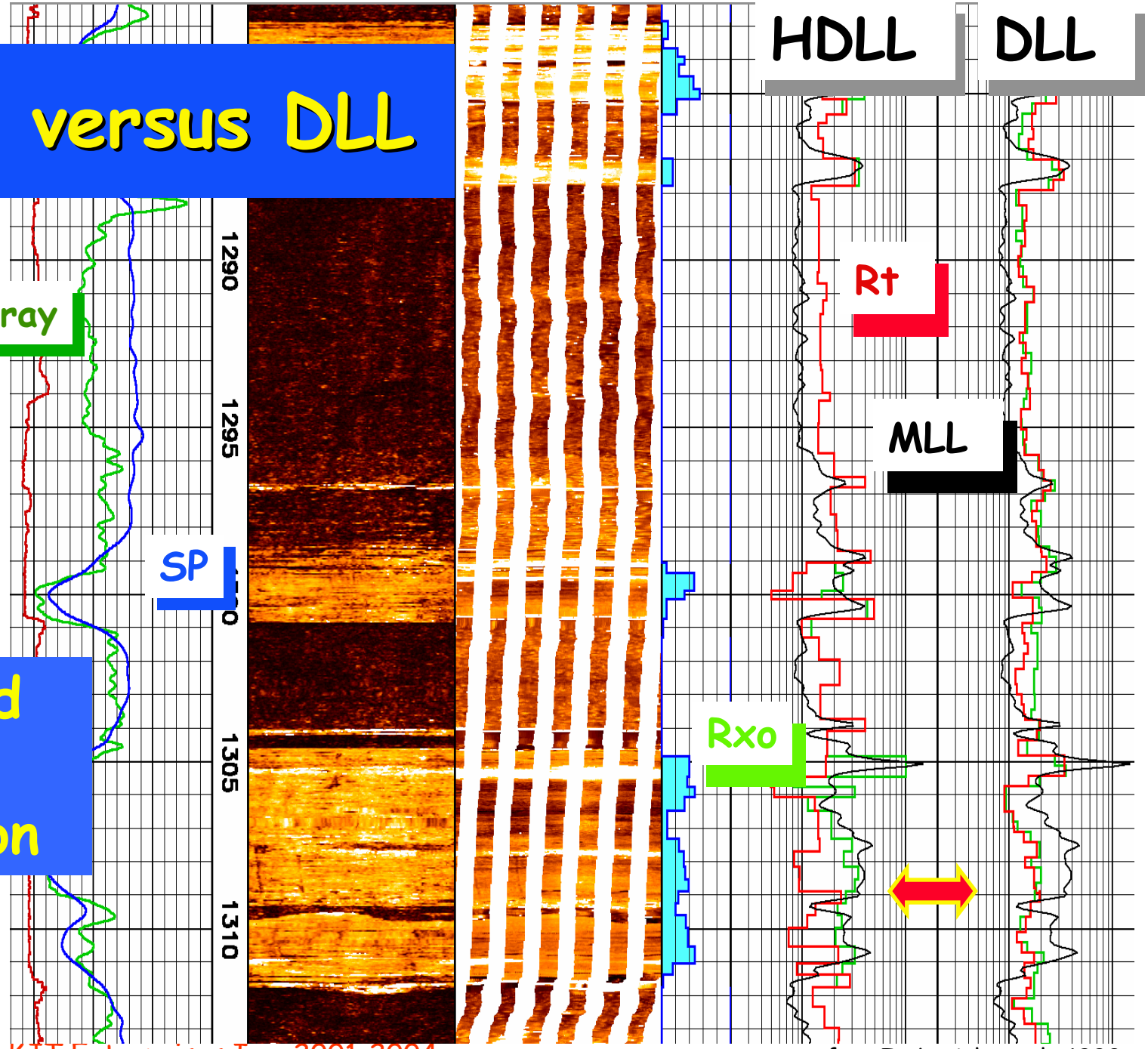
After Strack et al., 1998

Array laterolog objectives

- Next generation lateral instrument
- Resolve
  - thin beds (< laterolog- 2ft)
  - deep invaded formations
- Provide accurate radial profile of R_t & R_{xo}
  - invasion & flushed zone evaluation
- Provide risk analysis input
  - error bounds, parameter importance



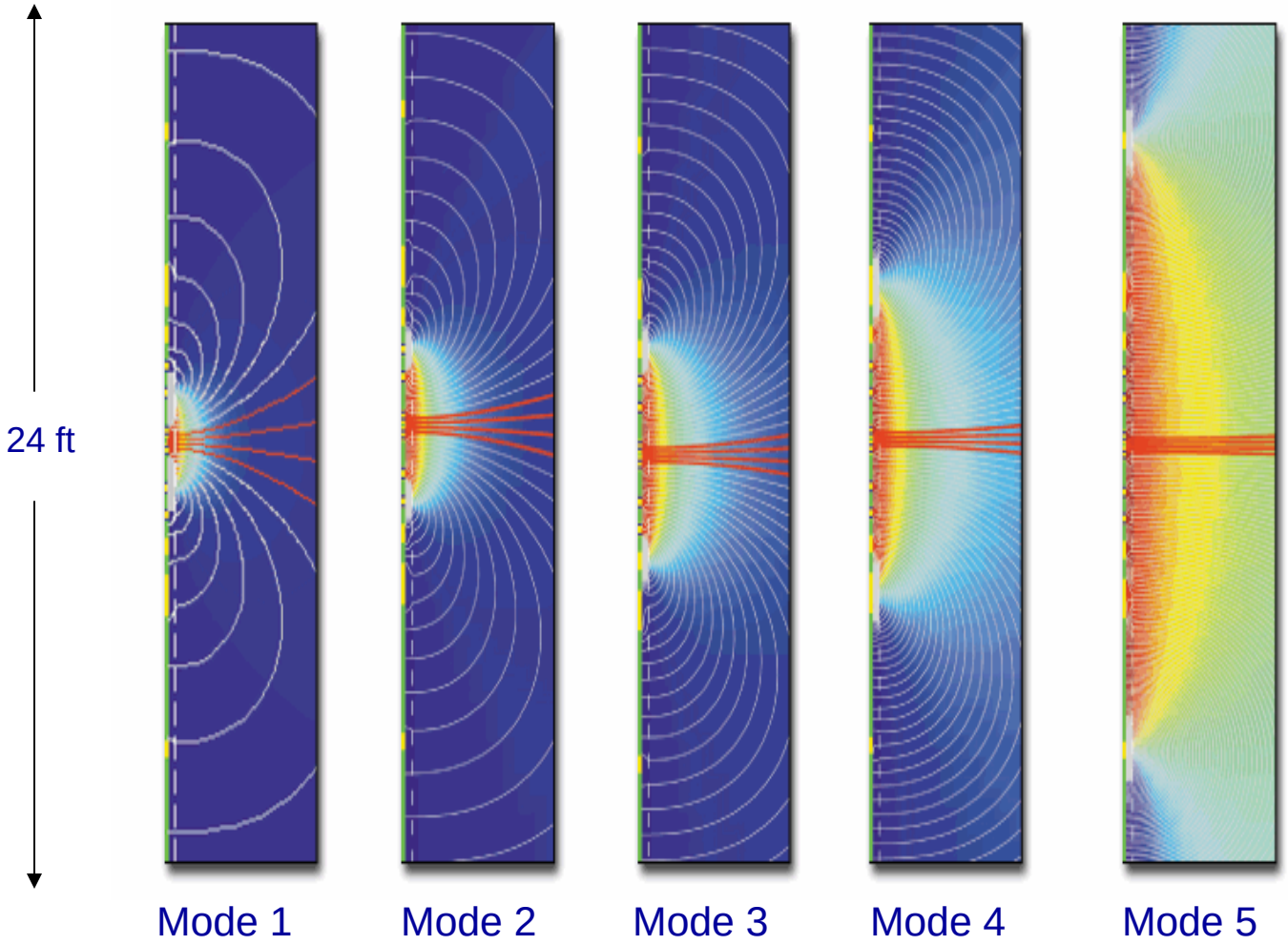
HDLL versus DLL



Improved vertical Resolution

After Itskovich et al., 1998

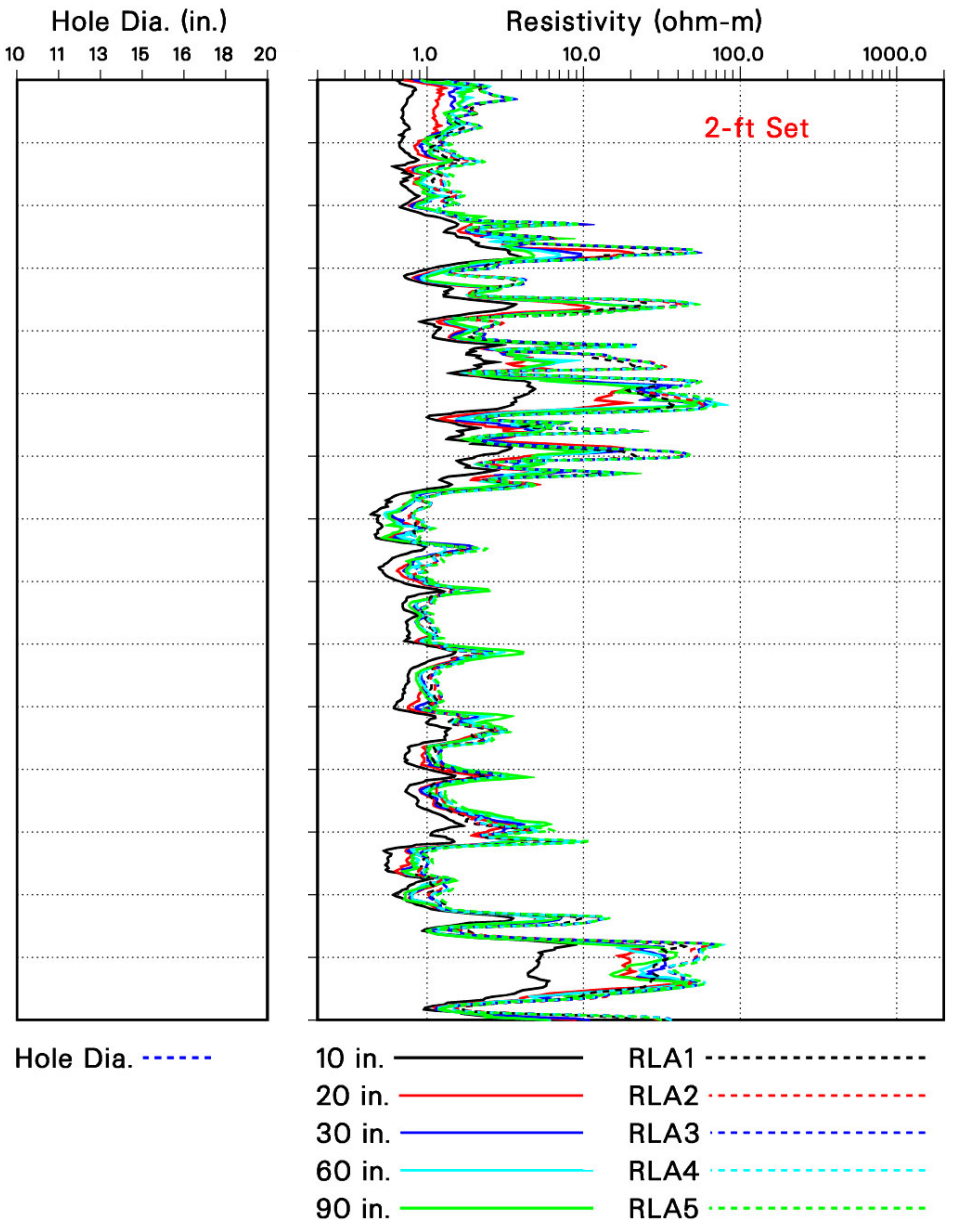
HRLA Principle and Modes



Courtesy of Barber, Schlumberger, 2001

Field Logs

- Main pay zone
- Gas sand
- Channel sand environment
- 8.5-in. bit
- R_m = .08 Ohm-m

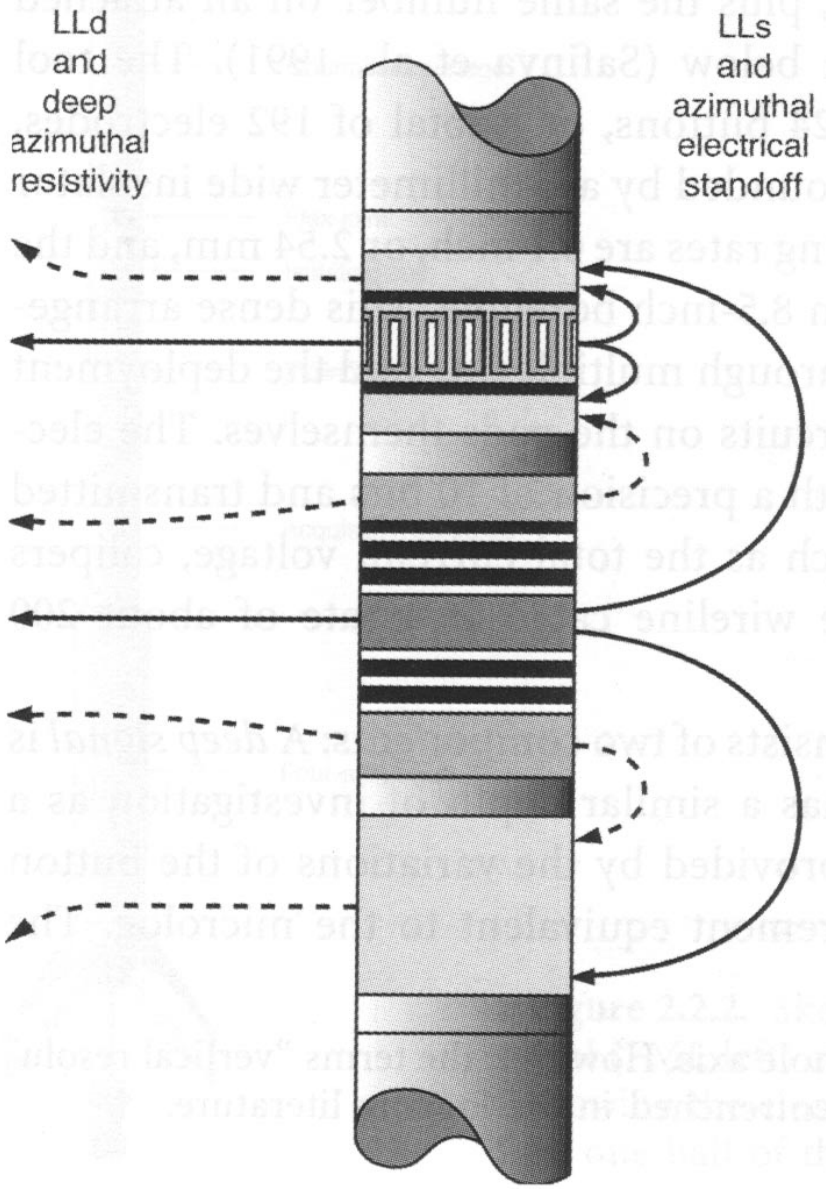


Courtesy of Barber, Schlumberger, 2001

Resistivity logging: Past, Present & Future

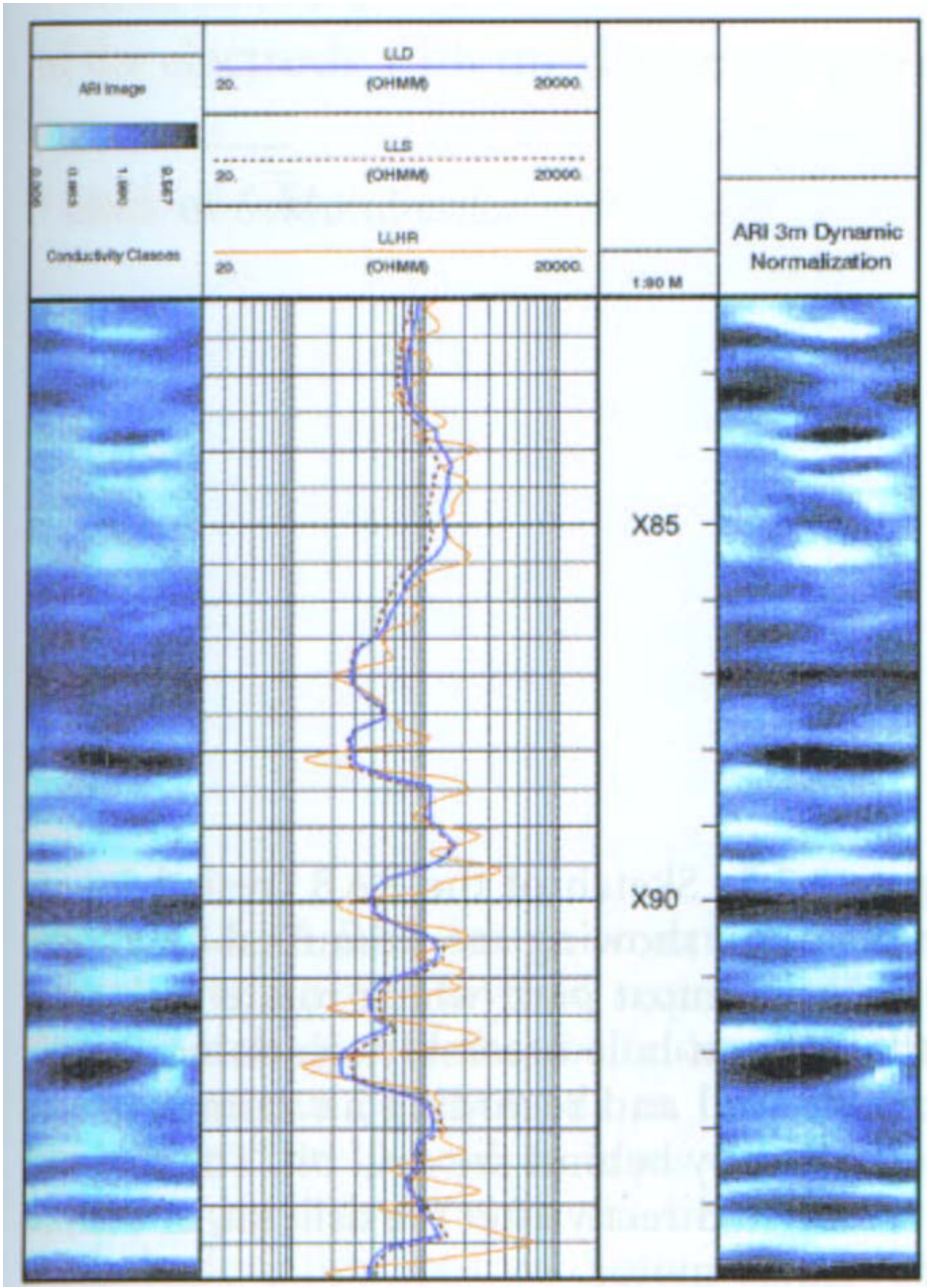
- Introduction
- Past
  - History
  - Older tools
  - Pitfalls
- **Present**
  - Overall concept
  - Improved tools
  - **Innovative tools**
    - **Azimutal image**
    - **3D induction**
    - **Through Casing Resistivity**
  - Interpretation
- Future

Azimuthal resistivity imager (ARI™)



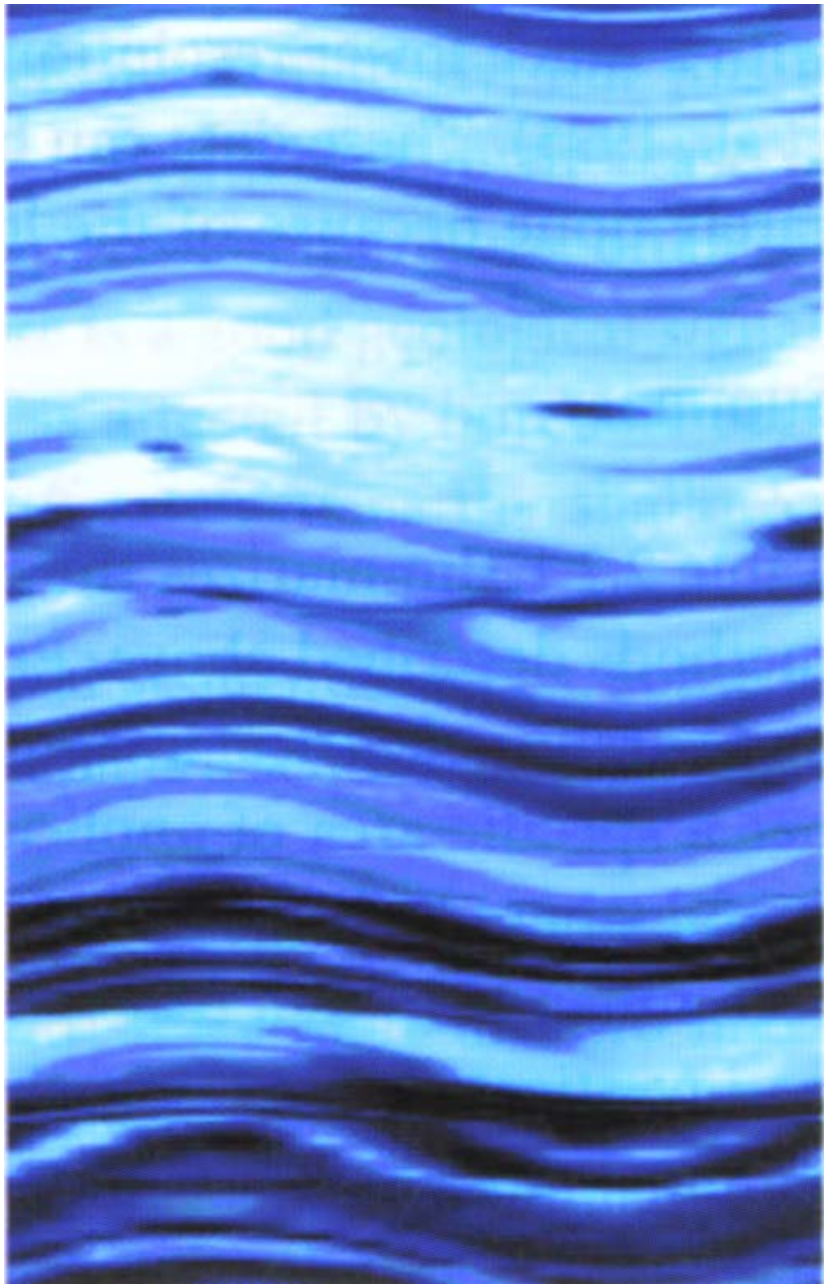
After Luthi, 2001

ARI™ example



After Luthi, 2001

ARI™ detailed example



After Luthi, 2001

Resistivity tools

- Laterologs
- Induction logs
- Thin bed tools
- Azimuthal resistivity imager
- Relationship to image tools
- Through casing resistivity
- 3D induction
- Inversion of resistivity logs

TCRL™: Benefits

- Bypassed hydrocarbons
- Monitor reservoir changes with time
  - water/gas flood control
- Better reservoir estimates
  - larger depth of investigation
  - optimized vertical resolution

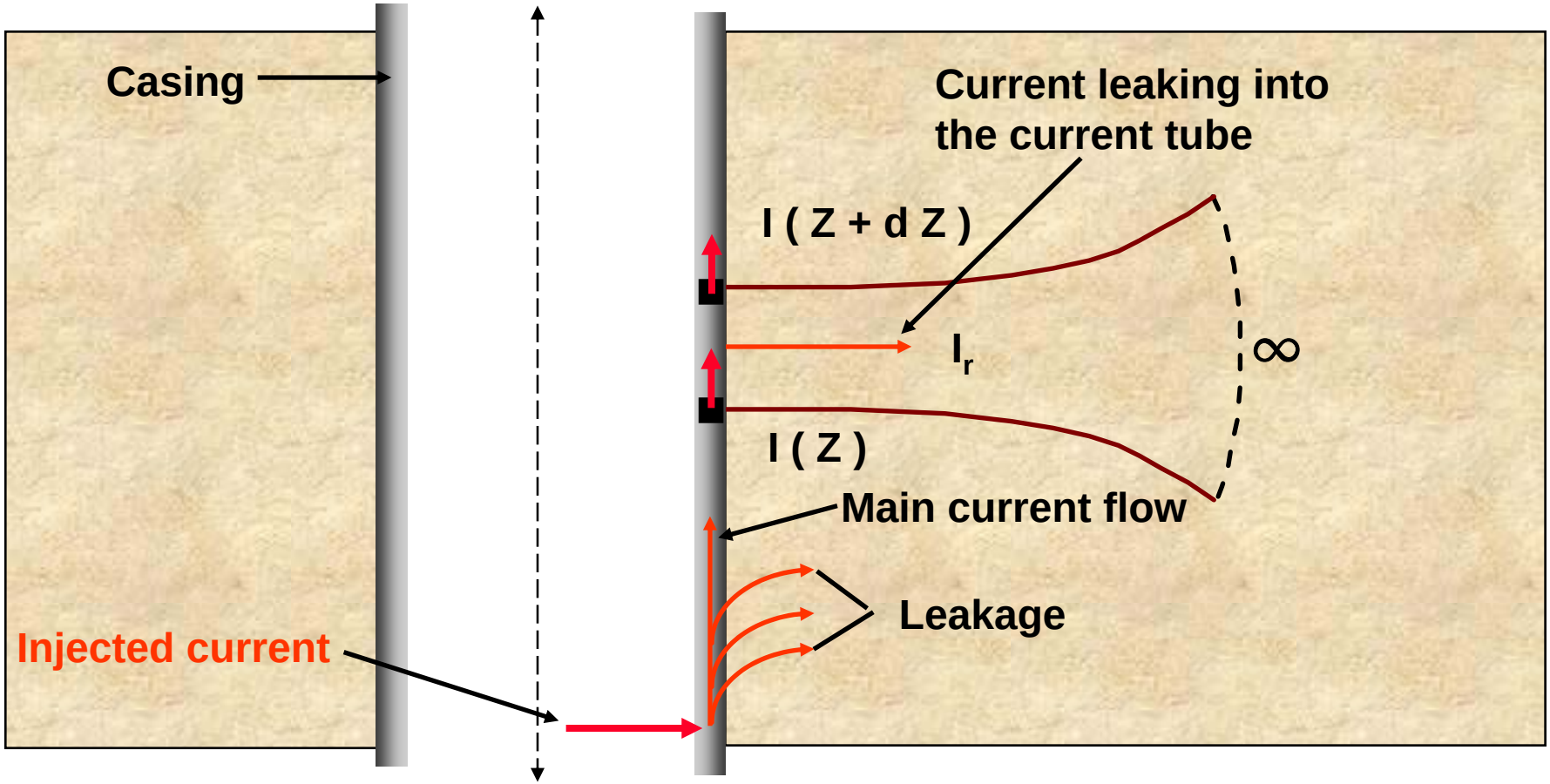
Strack, 1999

Basic history

• Three electrode scheme	-	Alpin (1939)
• Modern design	-	Kaufman (1990) Vail (1991)
• WA feasibility study	-	May-Nov. 1993
• Colorado test	-	Dec. 1993-Mar. 1994
• PML acquisition by BA	-	Q4 1997
• First digital log, BA Texas	-	5/98
• SLB commercial service	-	1999
• BHI cancel project	-	2000

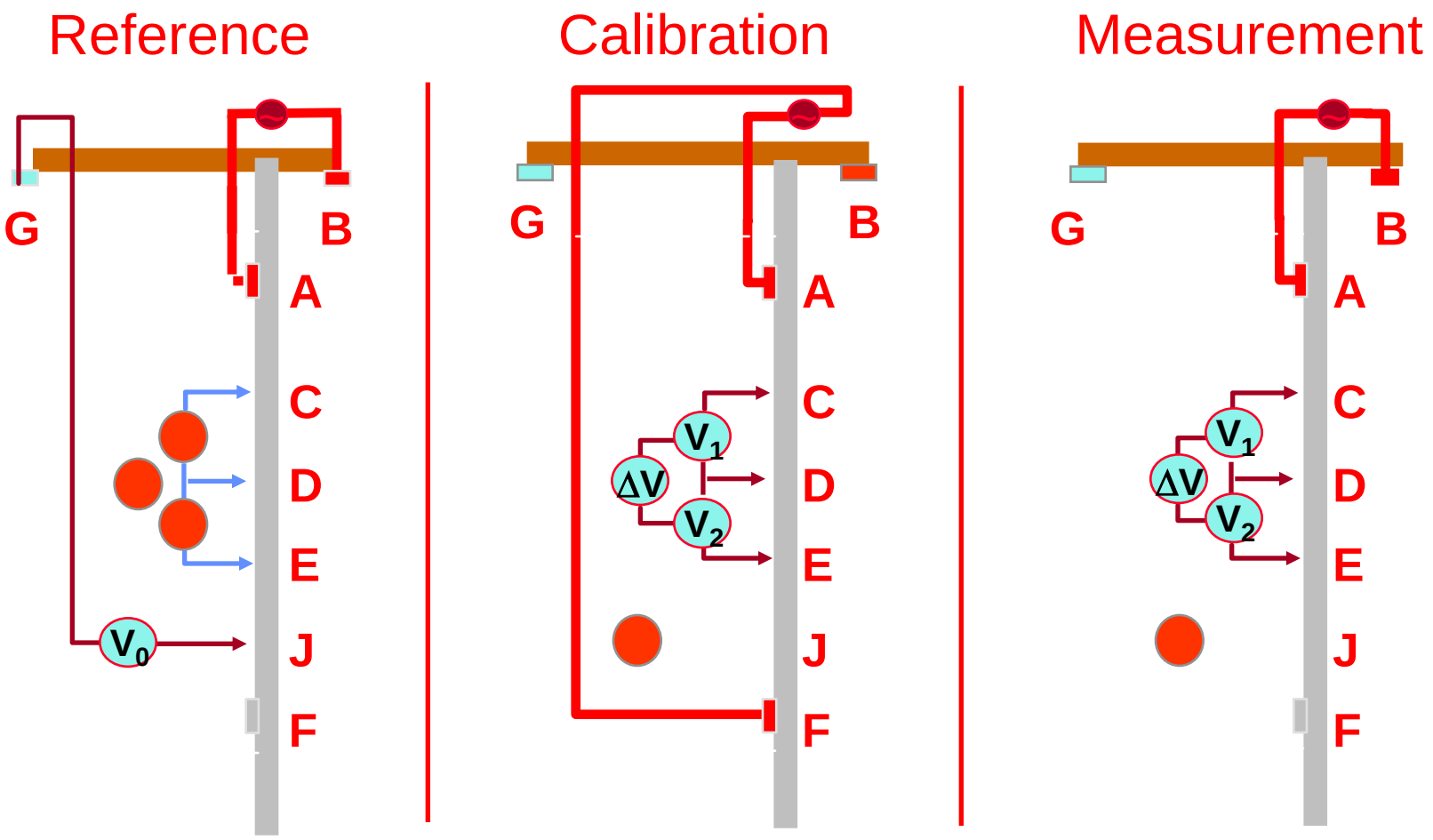
Strack, 1999

TCRL principle of operation



Strack, 1999

Operational modes

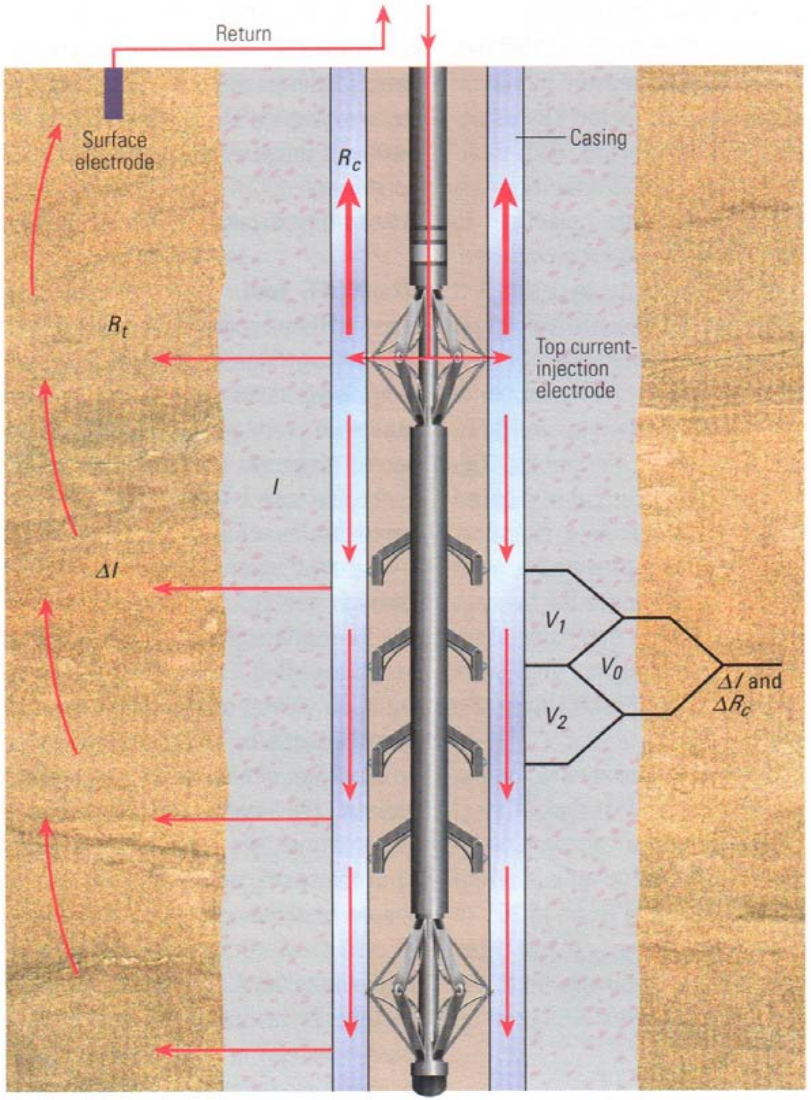


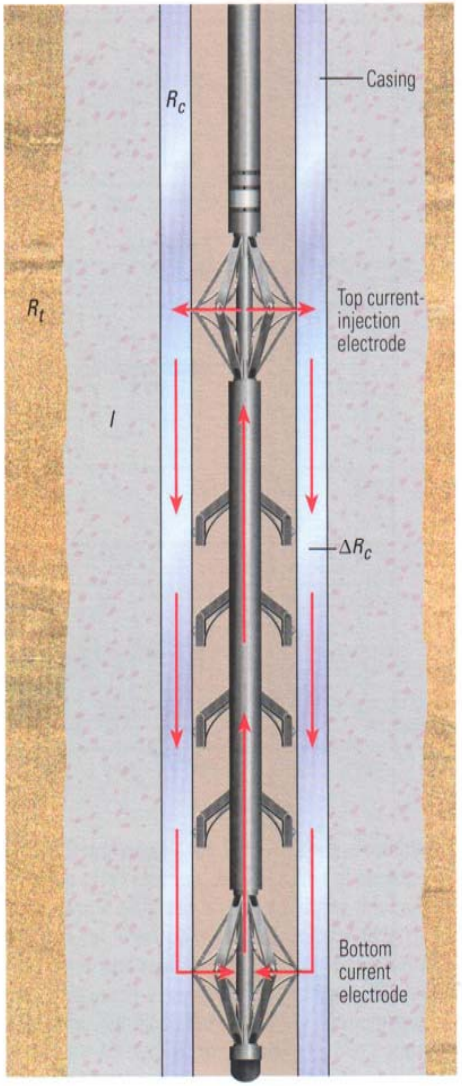
Strack, 1999

TCR tools at Baker Atlas test well

Strack, 1999

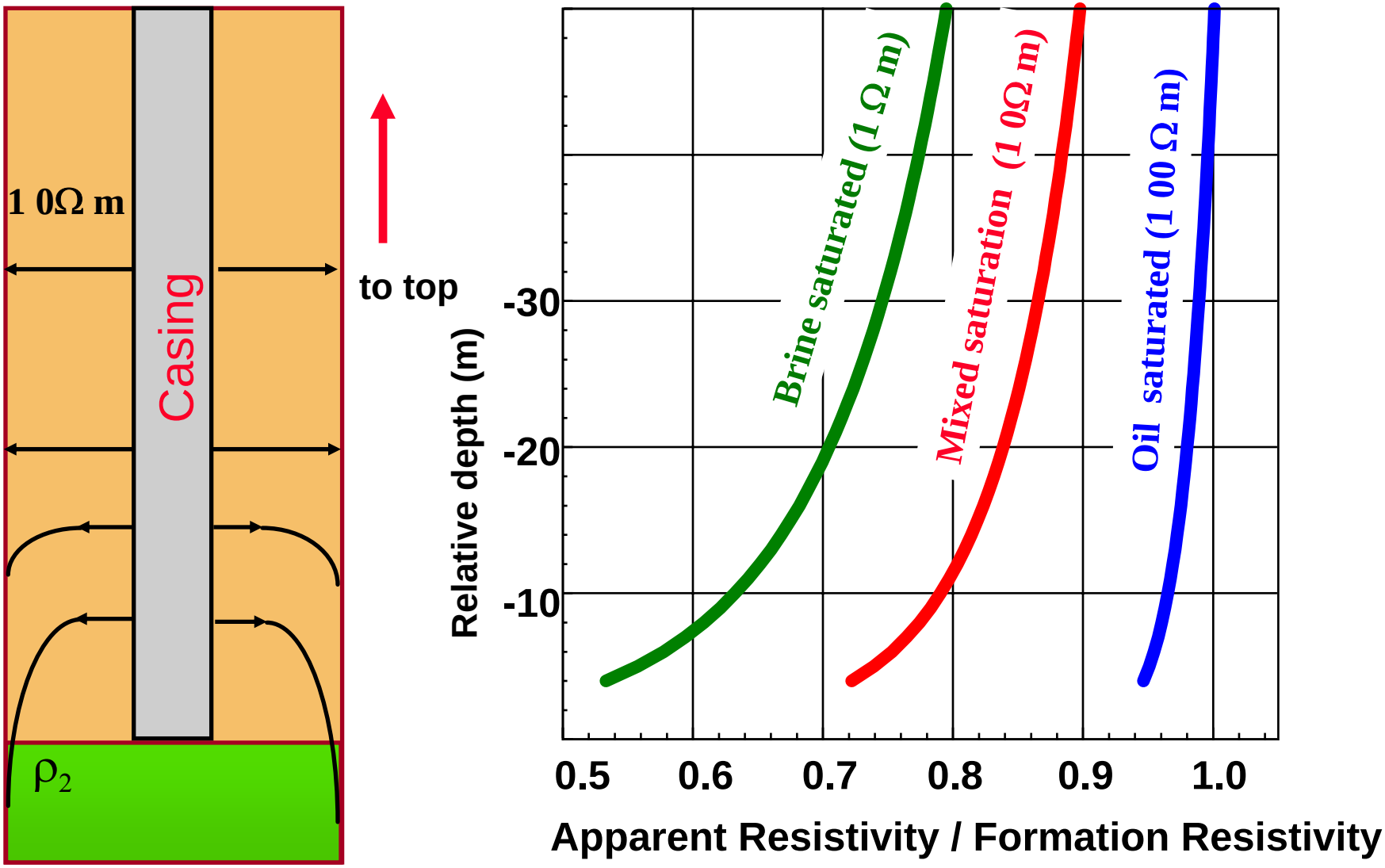
SLB: measurement & calibration





(Aulia et al., 2001)

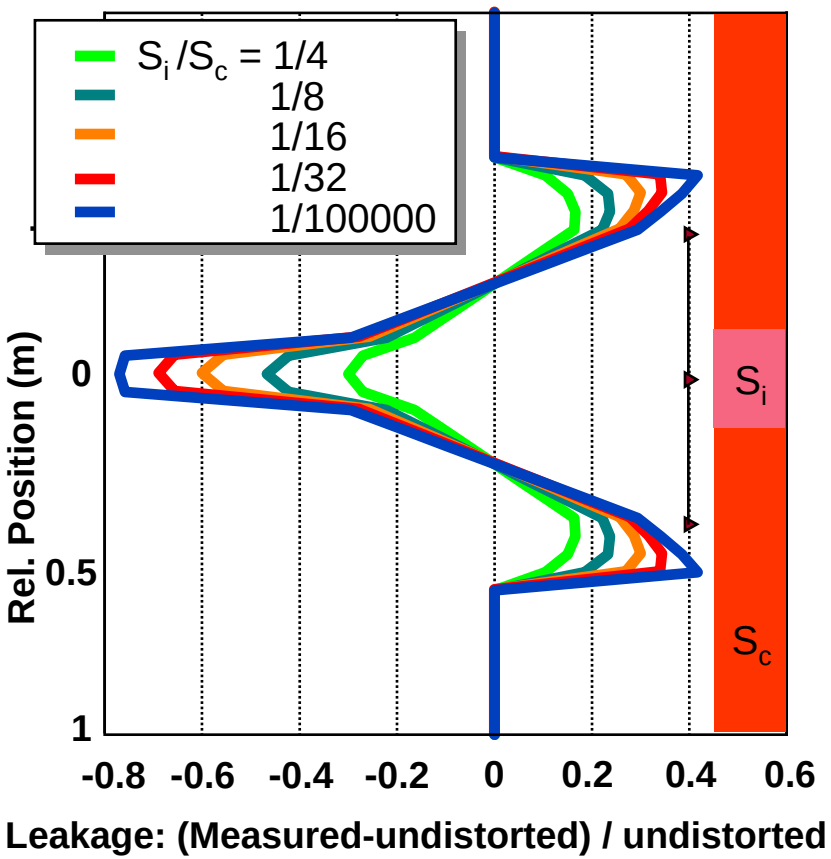
Casing shoe & reservoir depletion



Strack, 1999

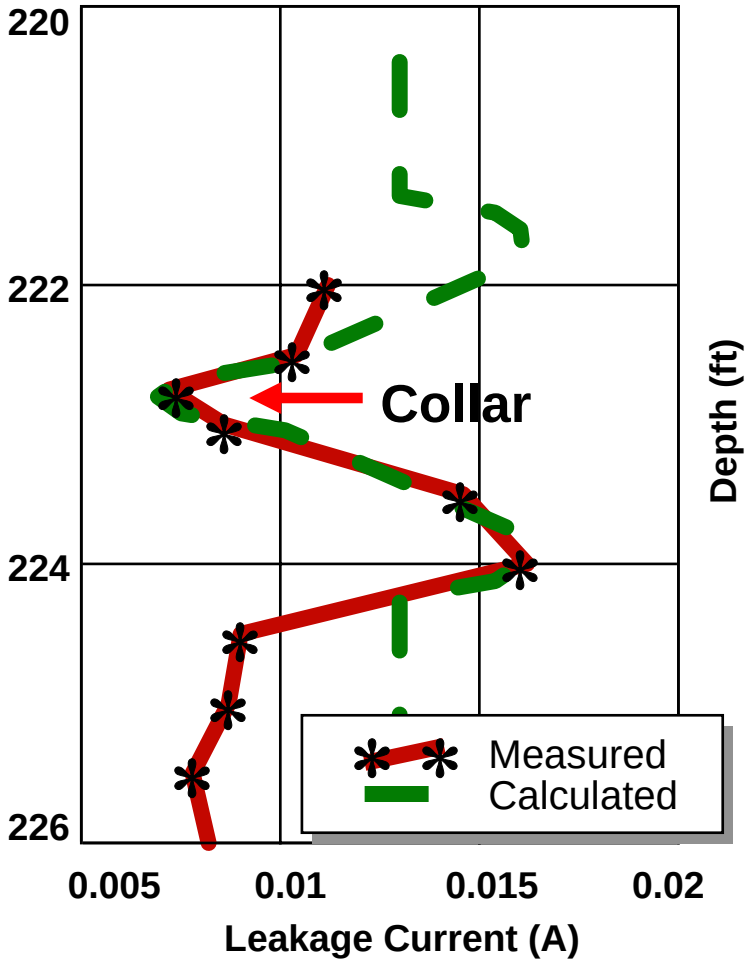
Casing collar effect (resistive)

Feasibility Study



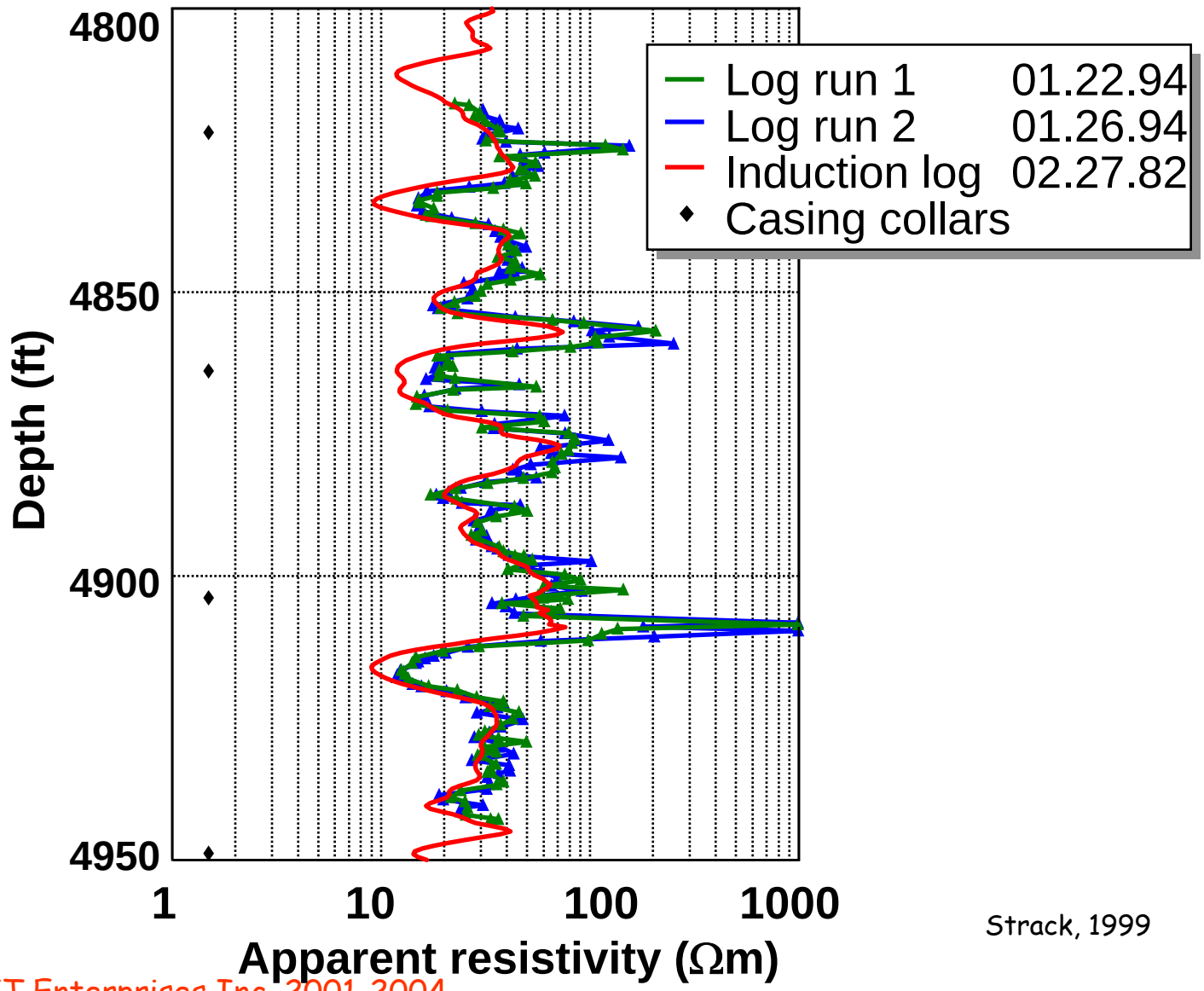
Link to original field plot

Test well



Strack, 1999

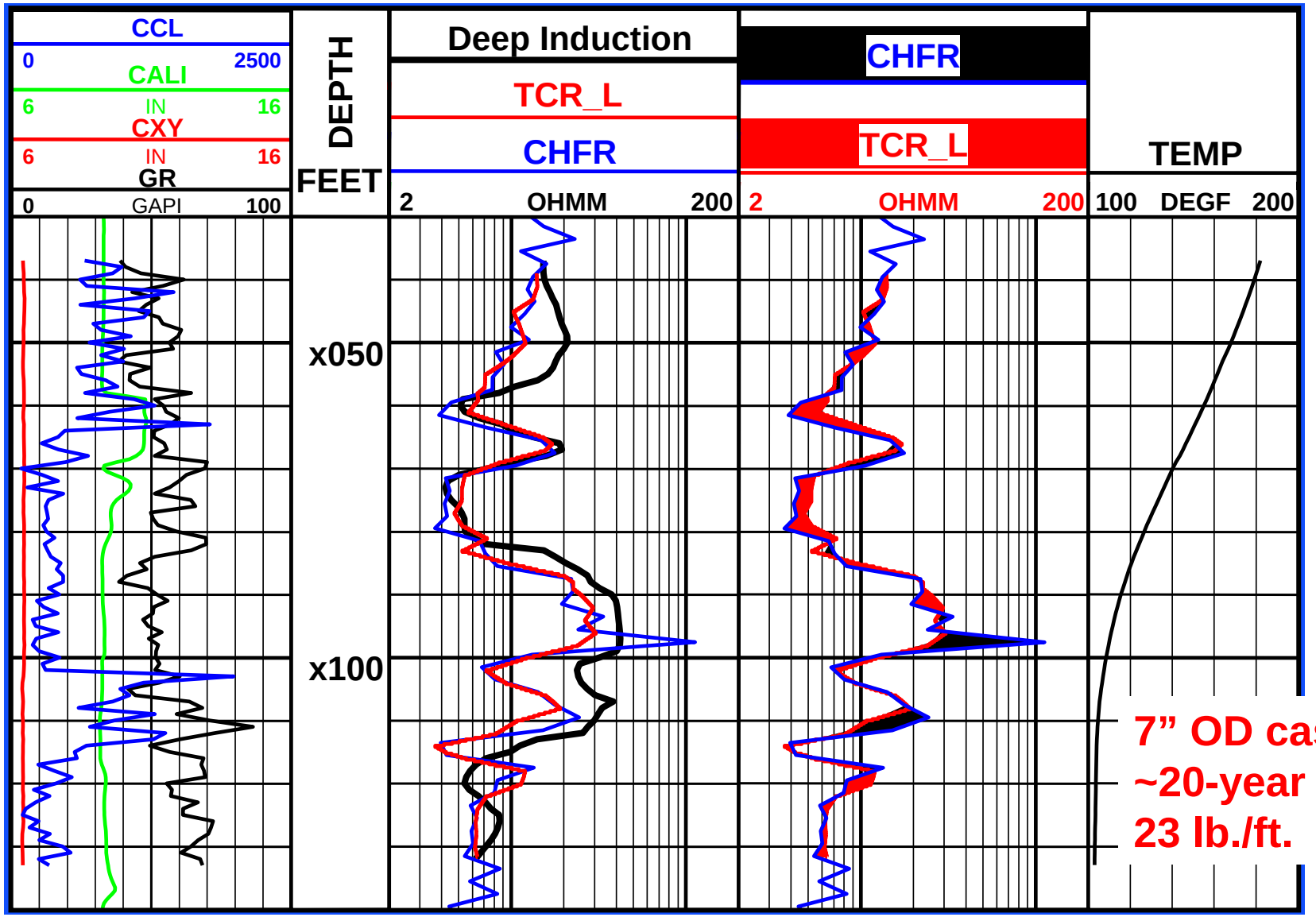
Colorado test: Blind test zone



Strack, 1999

TCR™ versus CHFR™

After Qiang et al., SPWLA 2002



Summary: TCR™

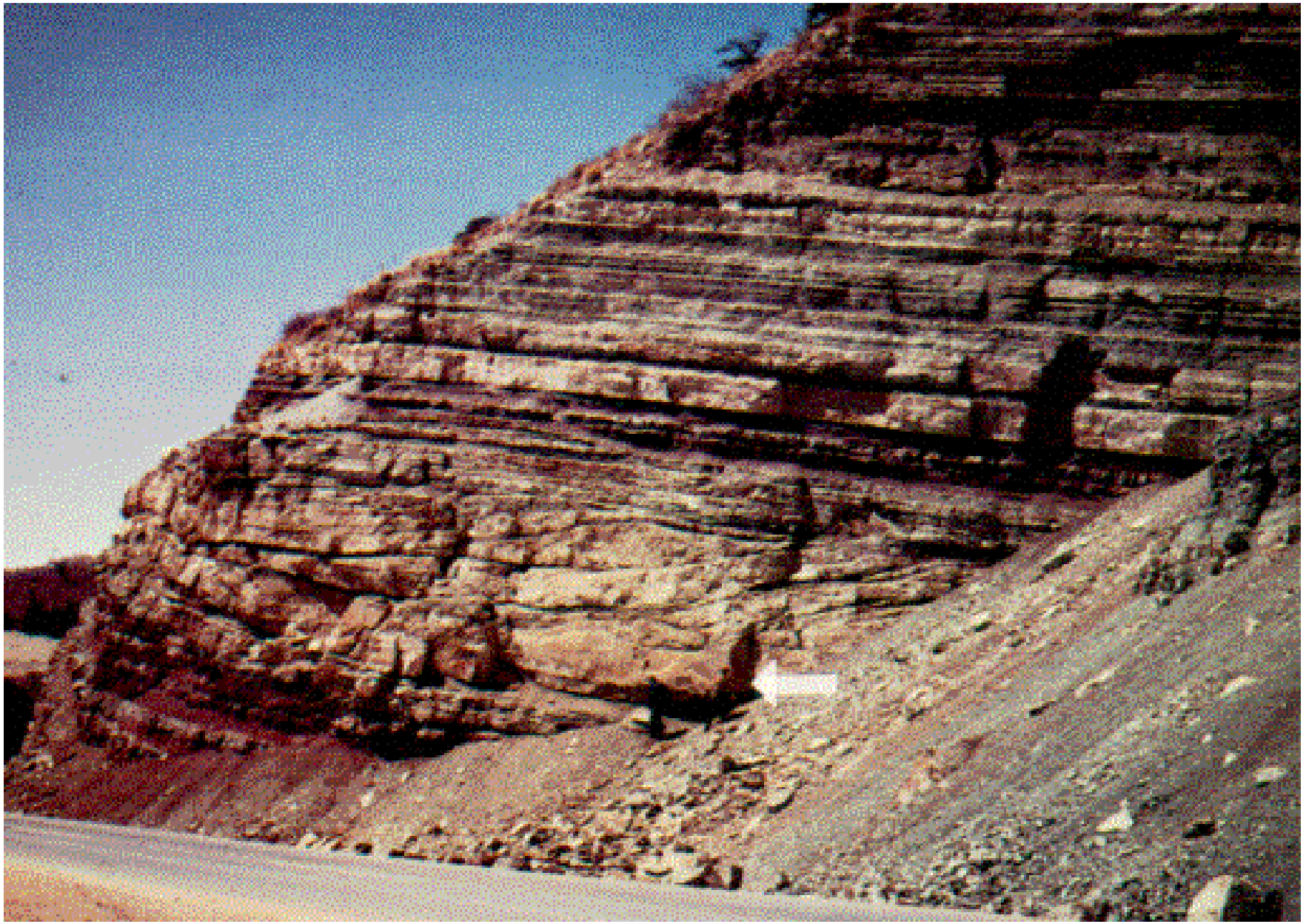
- TCR works: Schlumberger have working tools
- Numerical modeling predicted results
- It took 60 years from idea to tool
- Better commercial tools are still needed

After Strack 1998

Transverse Induction - history

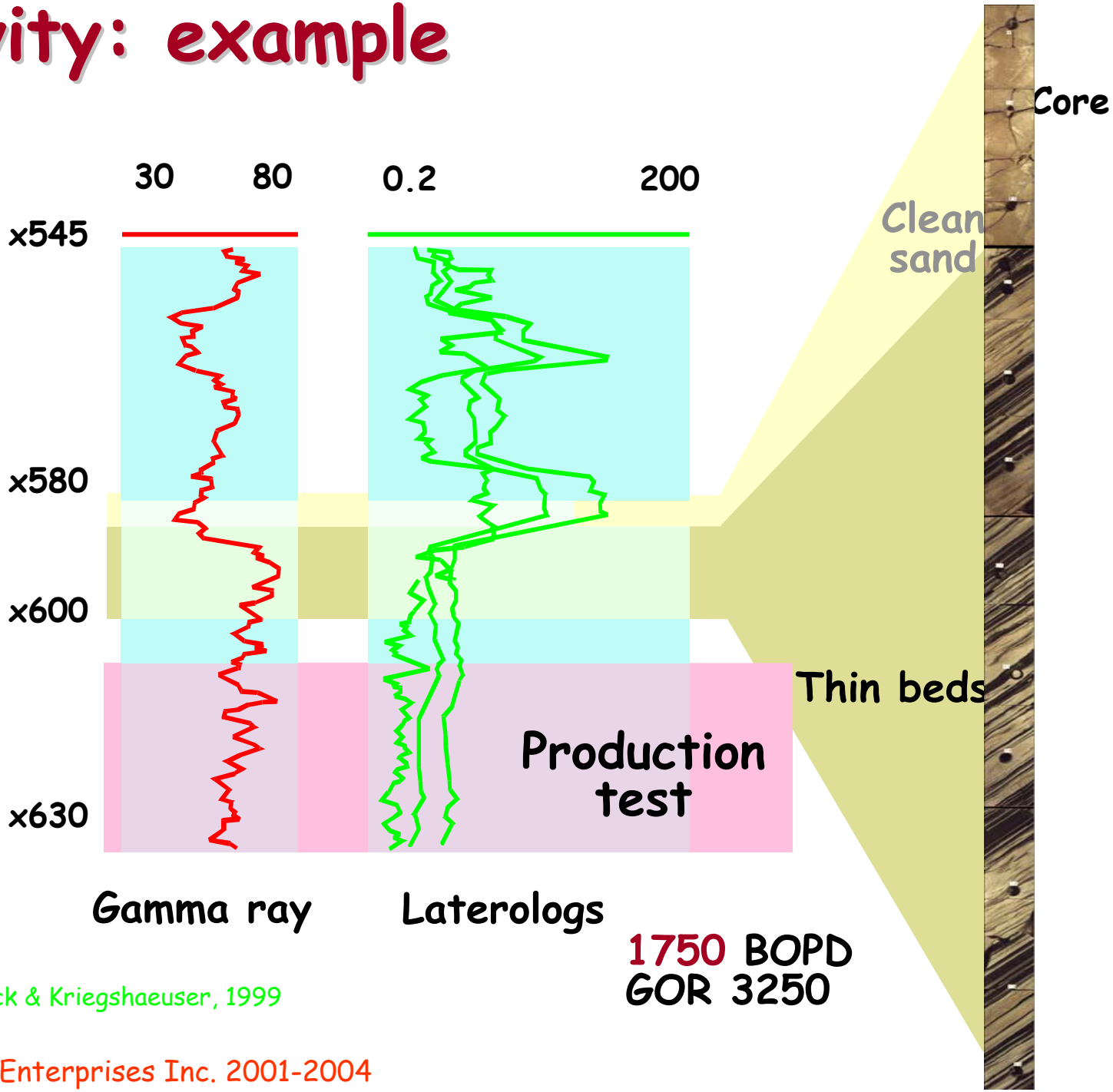
- Problem long known (Gianzero, Anderson, Klein & Allen etc)
- Commercial values recognized by Shell (1991)
  - 20 – 30% missed reserves
- Project concept developed Shell/WALS 1992/93
- Shell funded development by Baker Atlas
- Shell patents: Beard et al., 1998 – WO 98/00733; Strack et al., 2000 - # 6147496
- First TILT tool runs GOM, Oman 1999, name changed to 3DEX™
- SLB's equivalent tool 2003

Crossbeds & sand/shale & siltstones



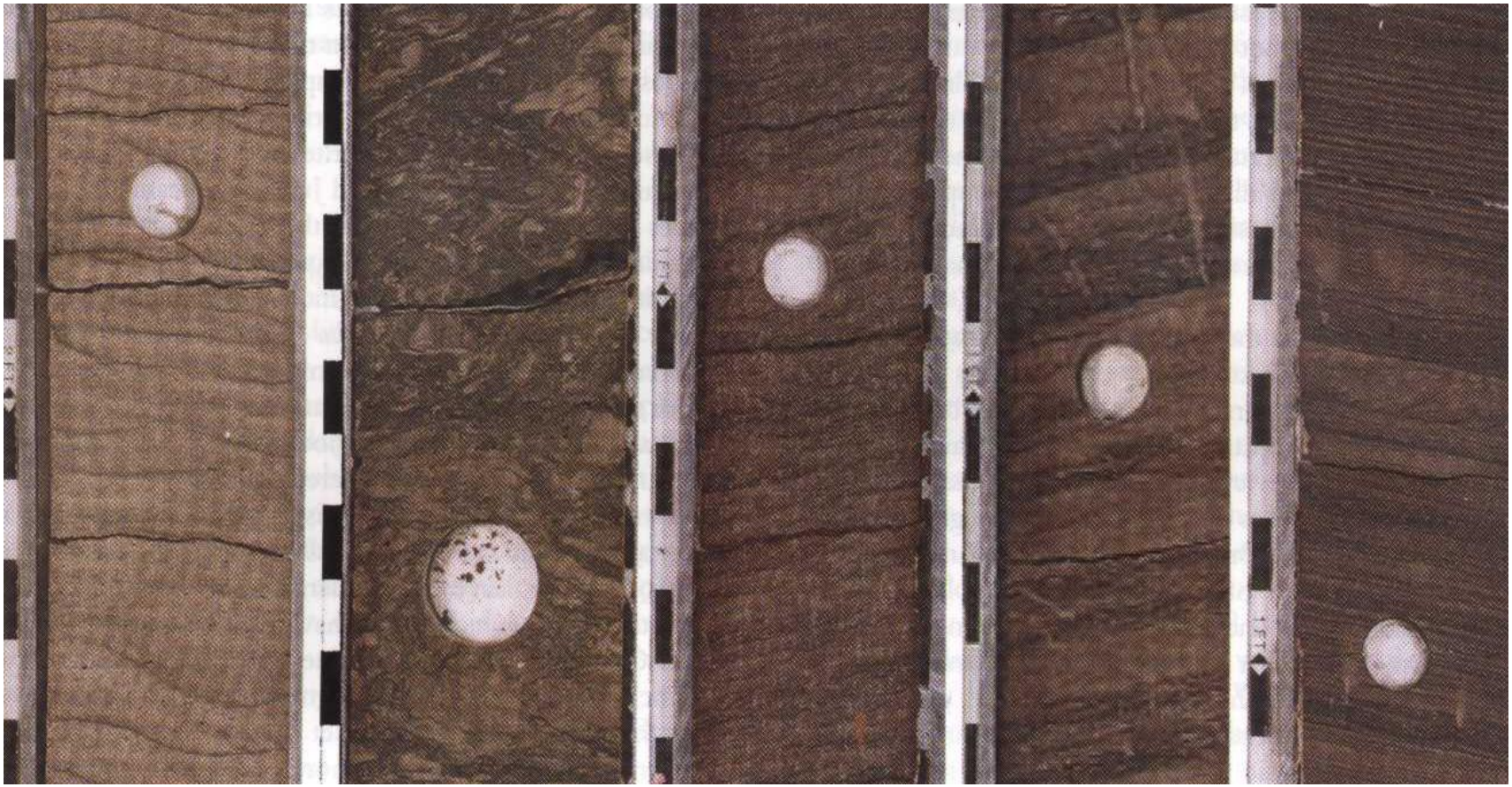
After Strack & Kriegshaeuser, 1999

Resistivity: example



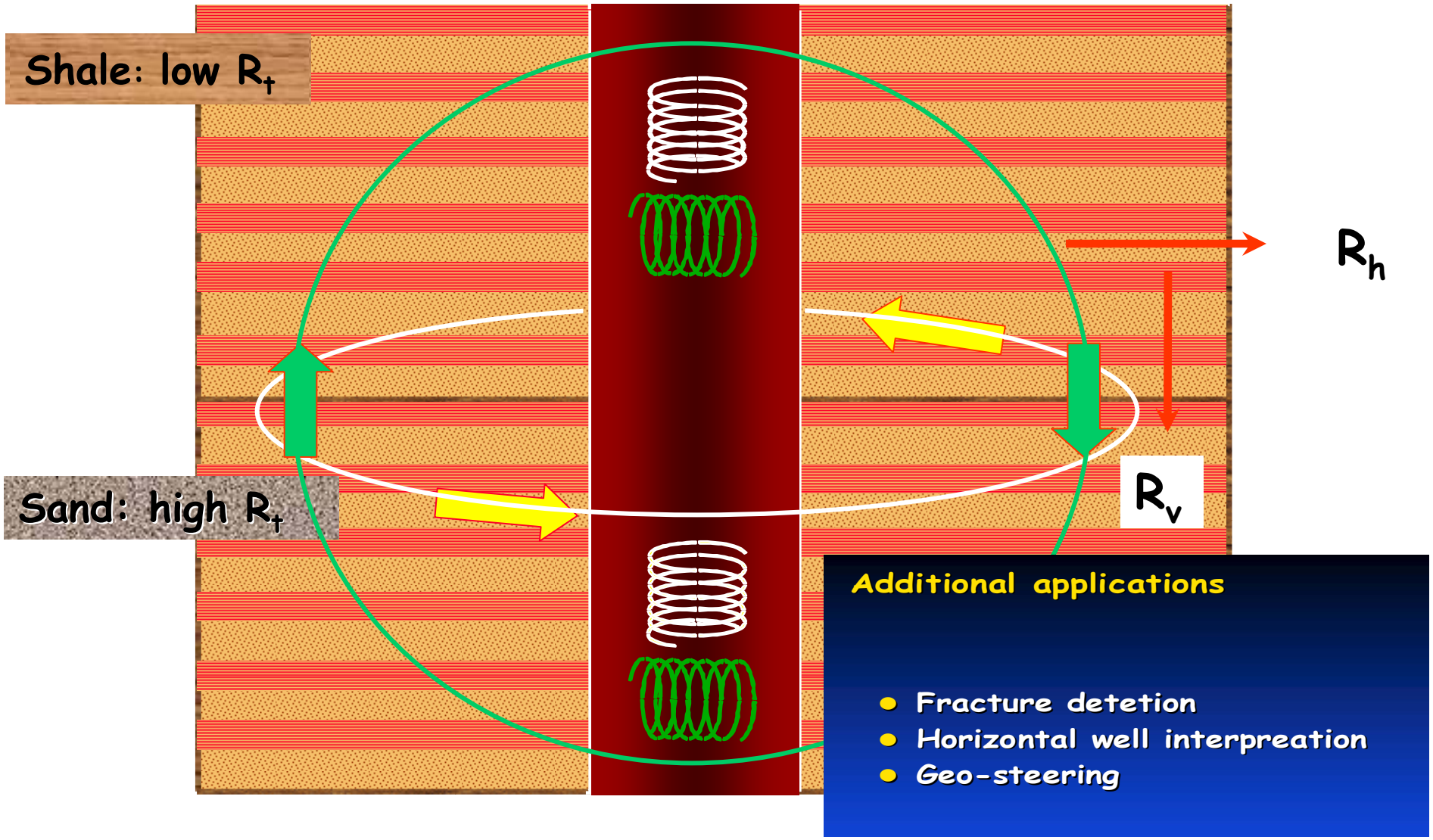
After Strack & Kriegshaeuser, 1999

Turbidite example



After Blackbourn & Thomson, 2000

Transverse Induction logging principle

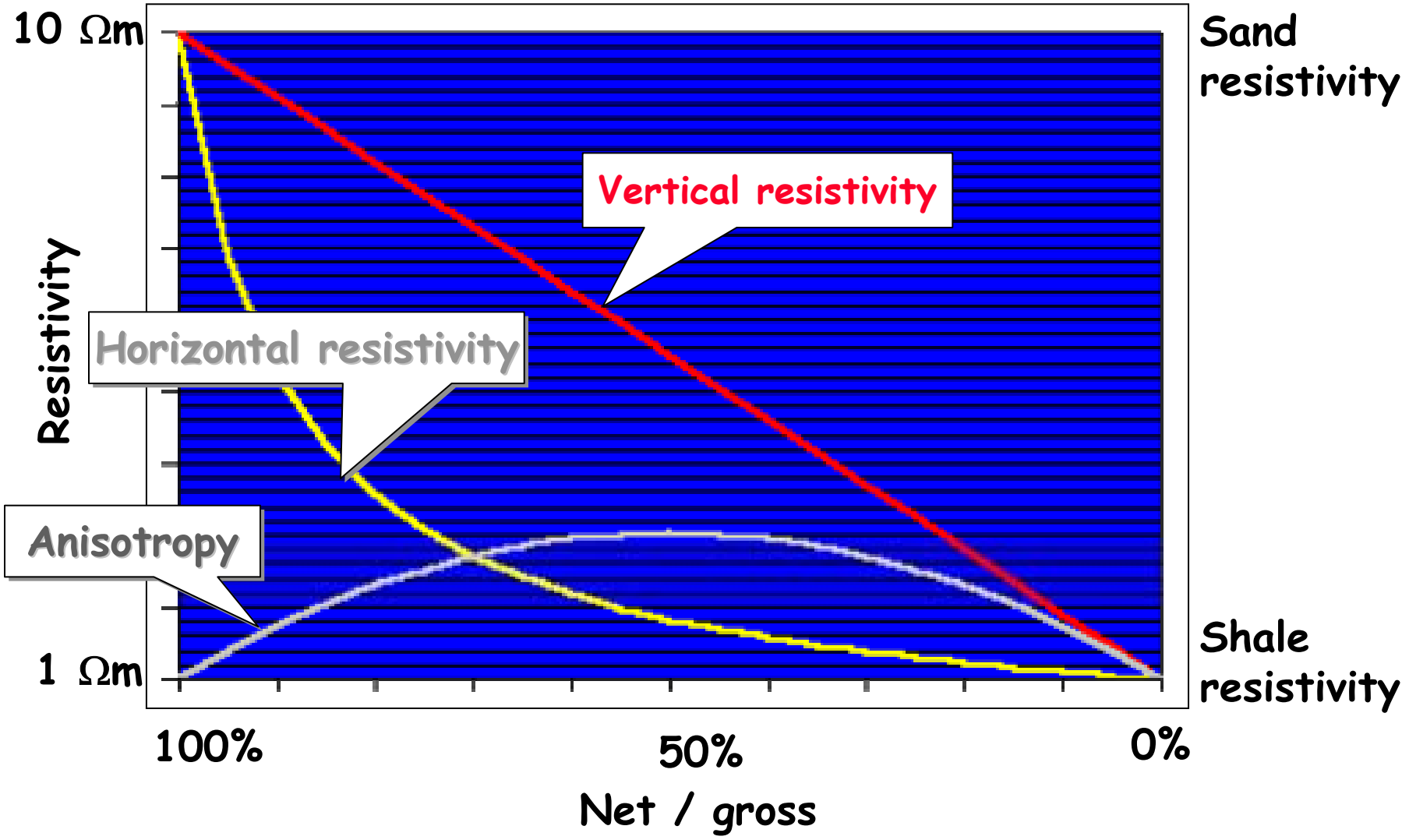


Additional applications

- Fracture detetion
- Horizontal well interpreation
- Geo-steering

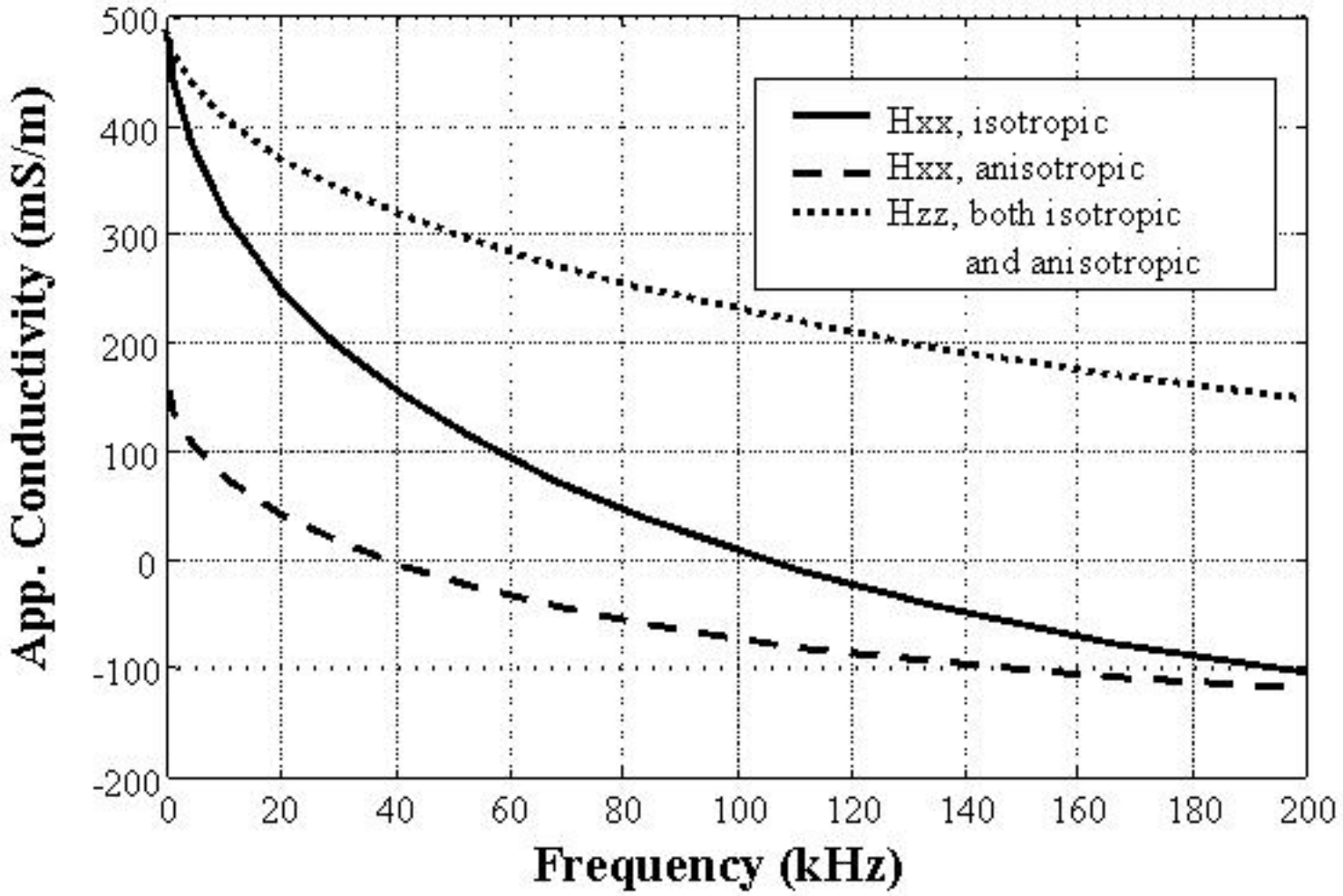
After Kriegshaeuser et al, 2000

Resistivities in laminar Sand/Shale sequences



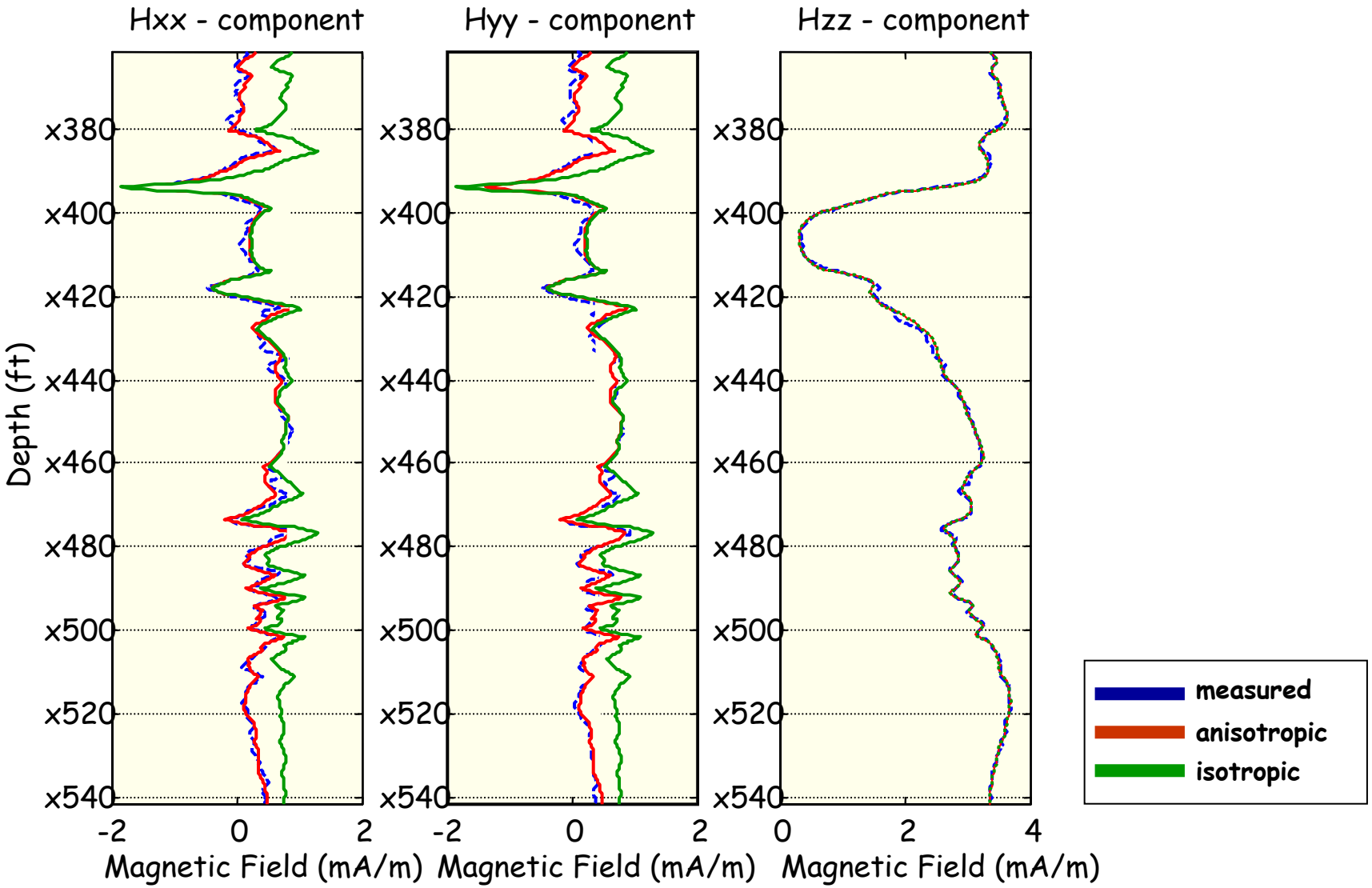
After Kriegshaeuser et al, 2000

Anisotropy influence on resistivity



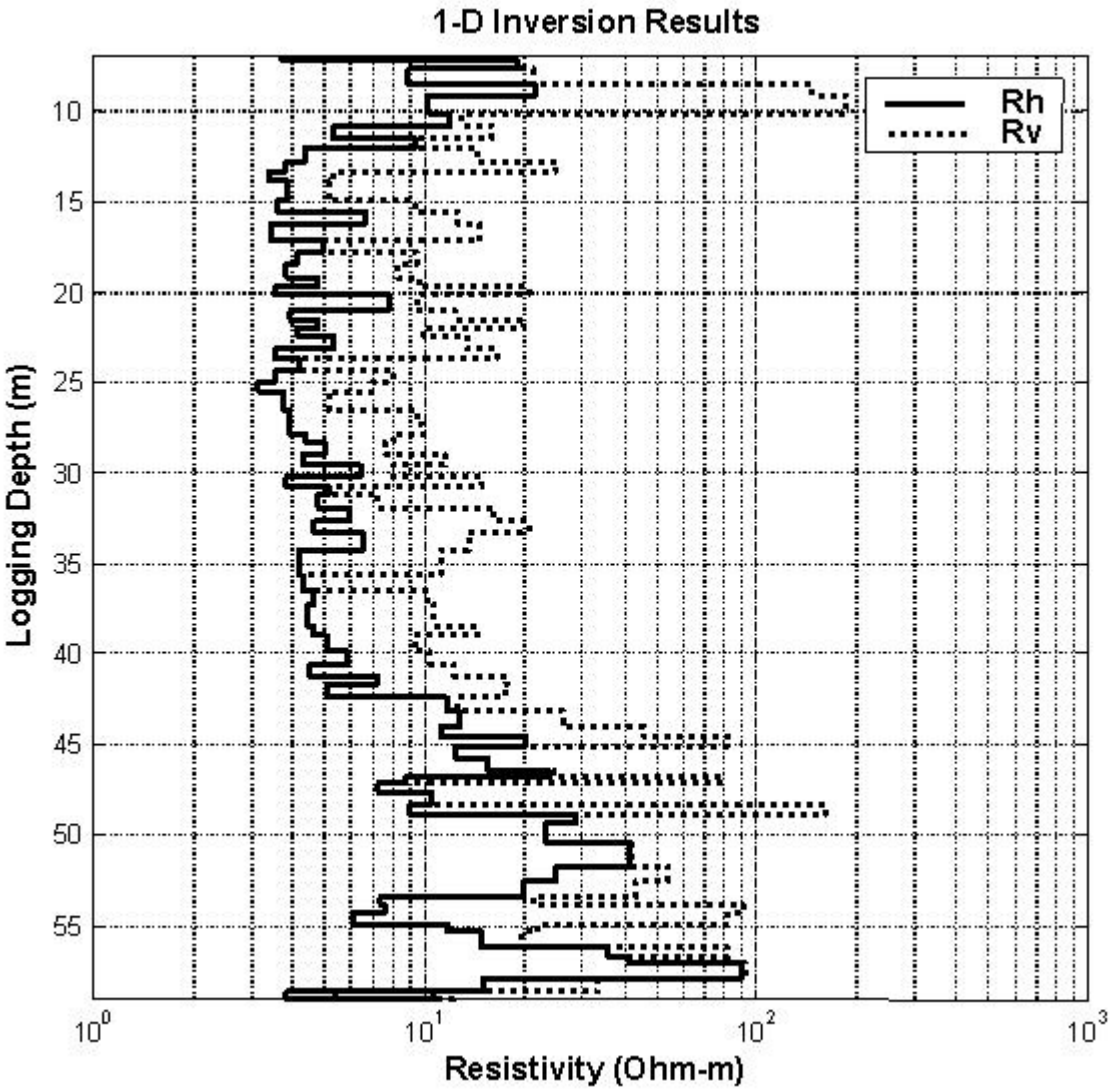
After Yu et al., 2001

Anisotropic vs. Isotropic data match



After Kriegshaeuser et al, 2000

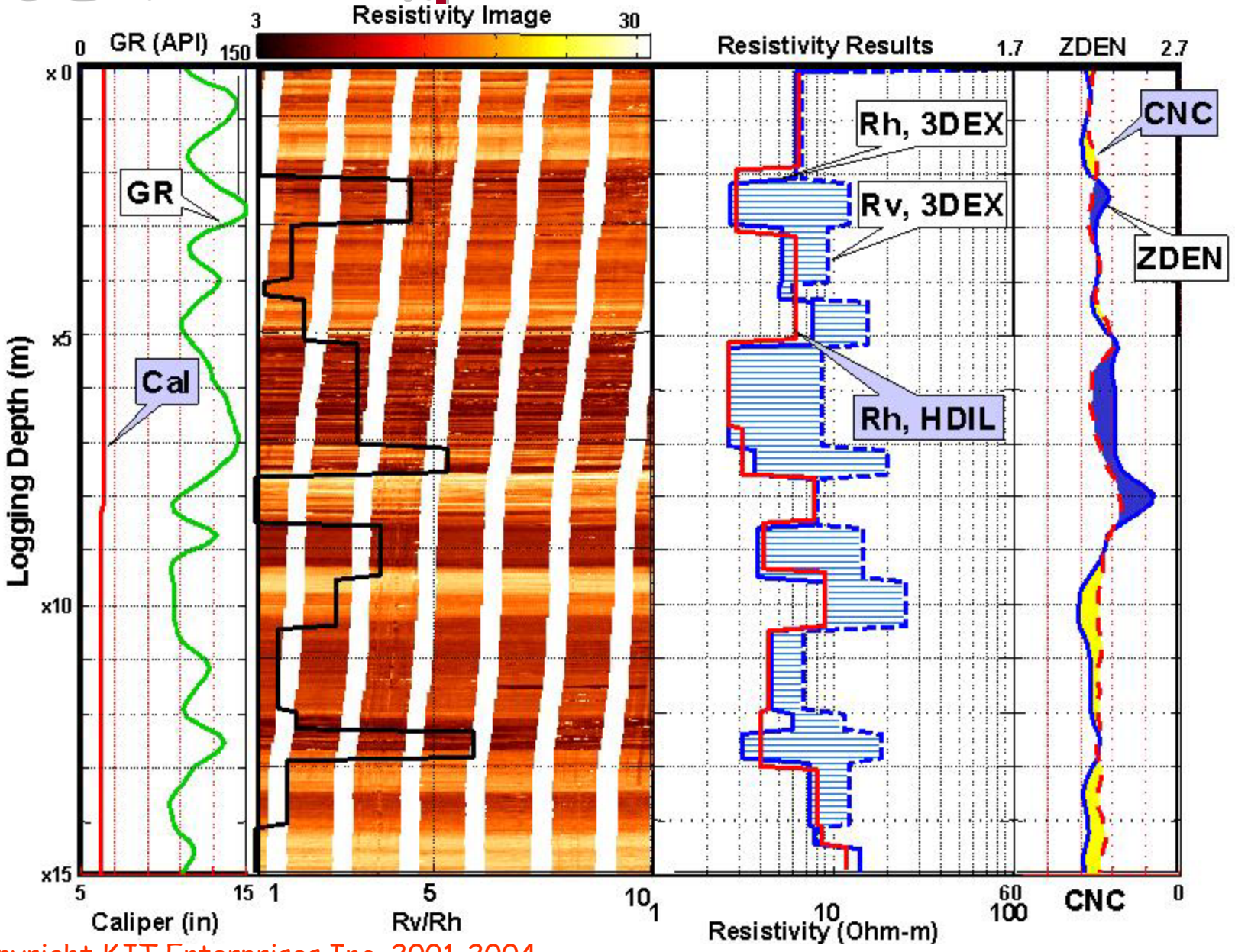
3DEX™: Inversion results



After Yu et al., 2001

3DEX™ example data

After Yu et al., 2001



Resistivity logging: Past, Present & Future

- Introduction
- Past
  - History
  - Older tools
  - Pitfalls
- **Present**
  - Overall concept
  - Improved tools
  - Innovative tools
  - **Interpretation**
    - **➔Modeling & inversion**
- Future

Resistivity tools

- Laterologs
- Induction logs
- Thin bed tools
- Relationship to image tools
- Through casing resistivity
- 3D induction, example
- Inversion of resistivity logs

Inversion Outline

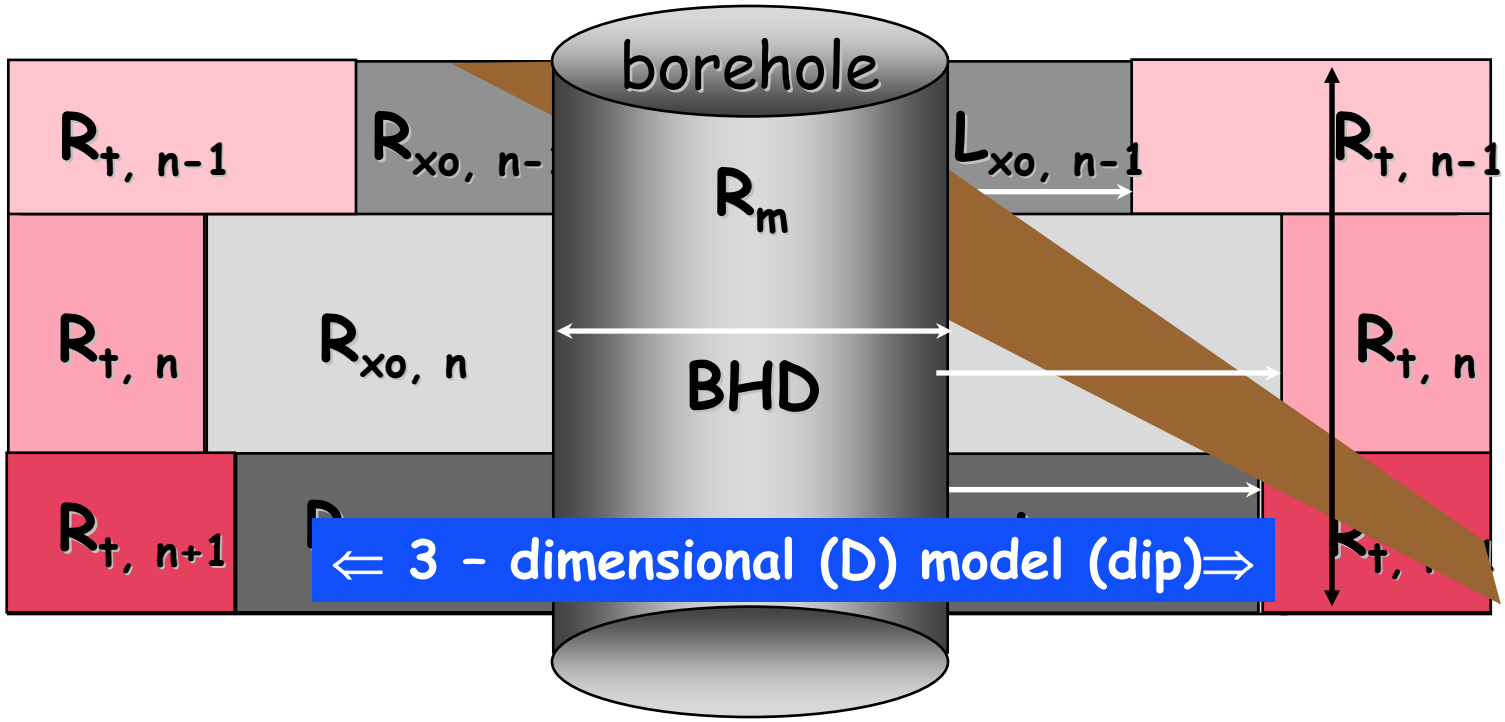
- **Inversion methodology**
- Practical implementation
- Case histories
- Conclusions

After Strack et al., 1998

Earth Models

⇐ 1 - dimensional (D) model (vertical) ⇒

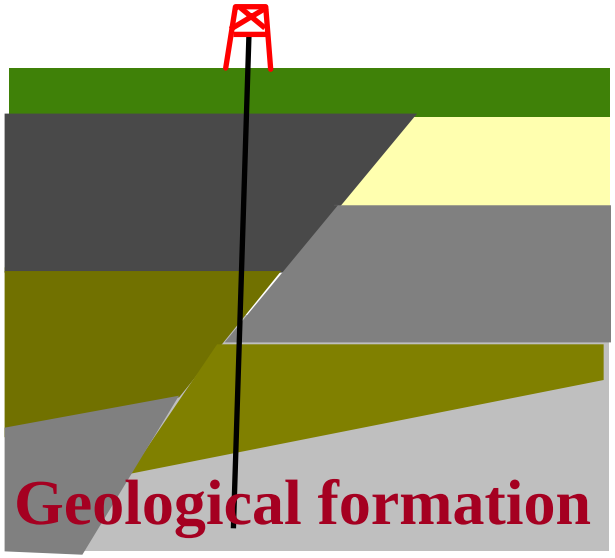
⇐ 2 - dimensional (D) (cylindrical) ⇒

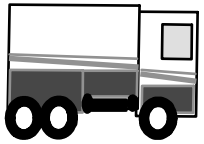


⇐ 1 - dimensional (D) model ⇒

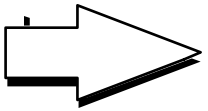
After Strack et al., 1998

Logging process

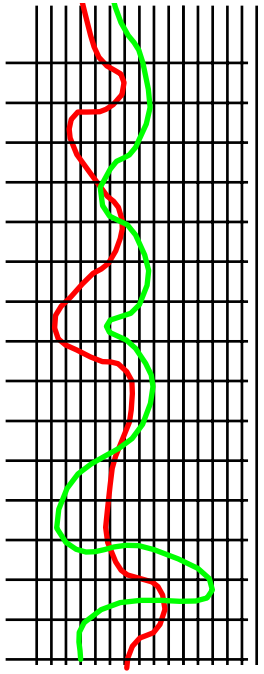




Measurements



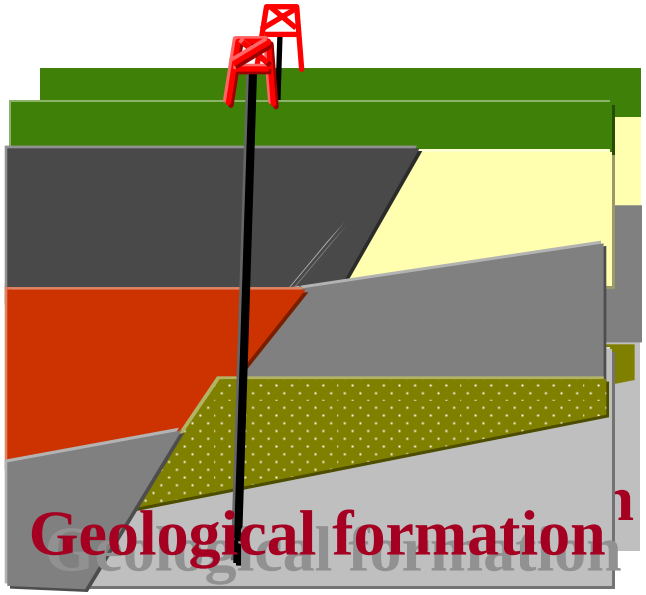
Logs



Earth model described by parameters (resistivity distribution)

Strack, 1999

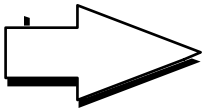
Modeling process for logs



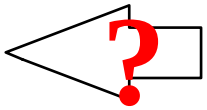
Logs

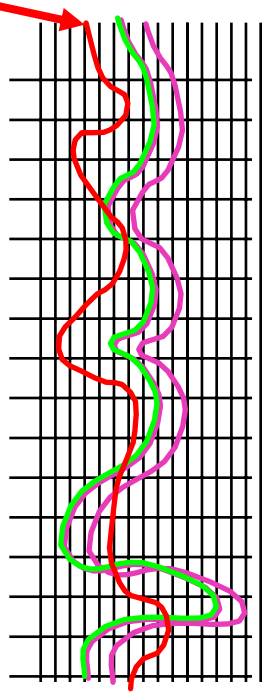
Modeled log data

Modeling



Inversion

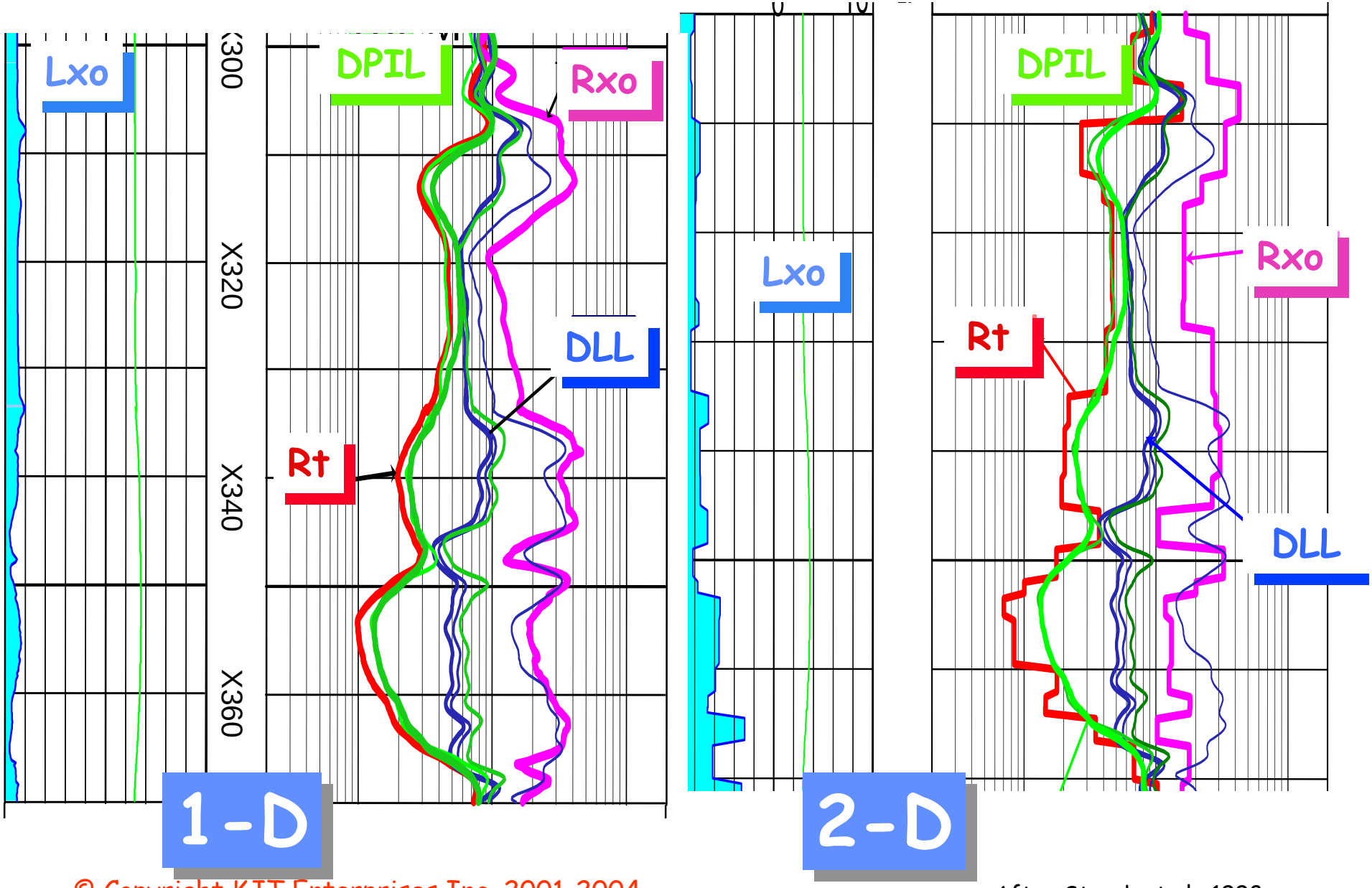




Earth model described by parameters (resistivity distribution)

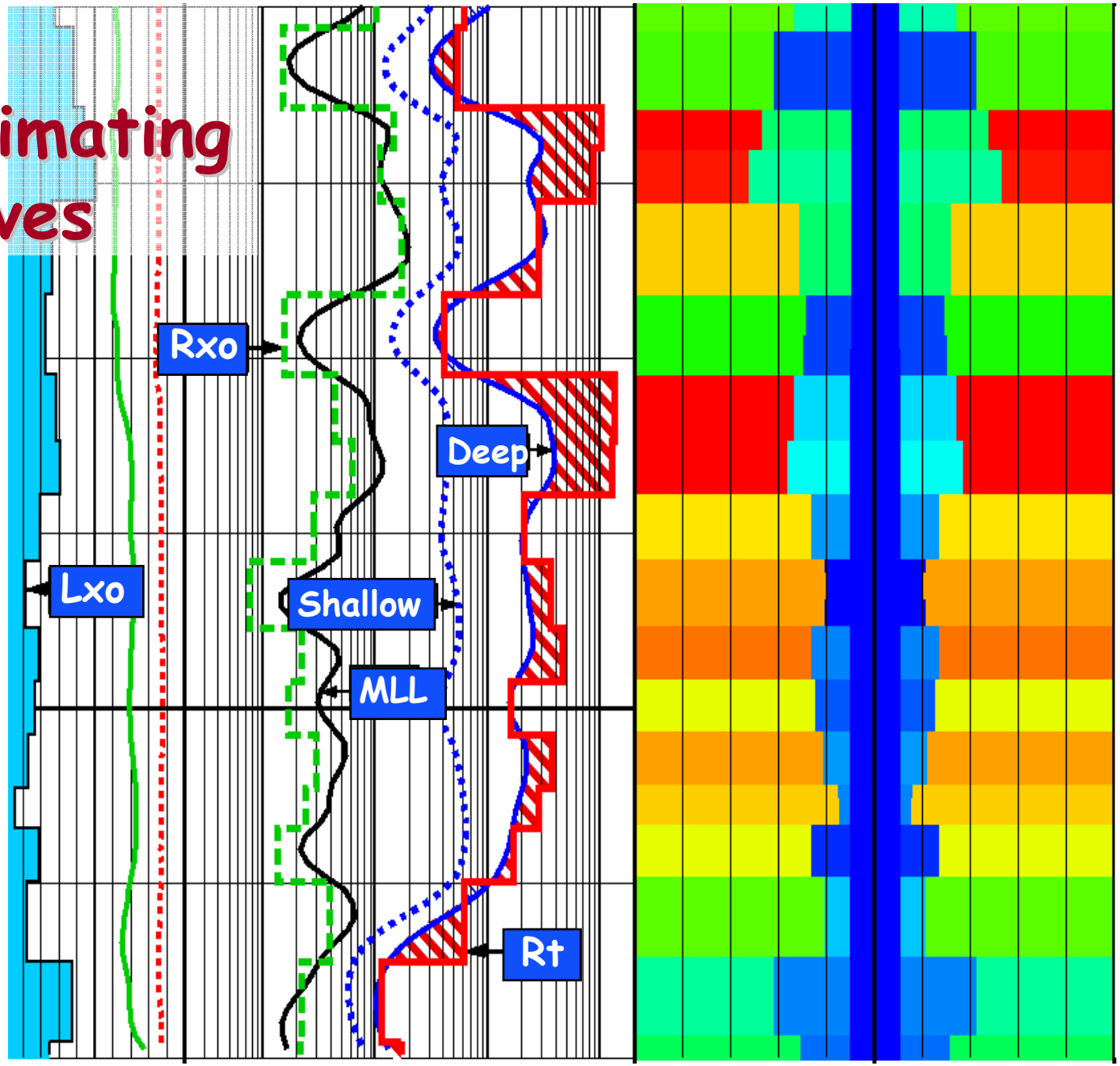
Strack, 1999

Inversion: 1D versus 2D

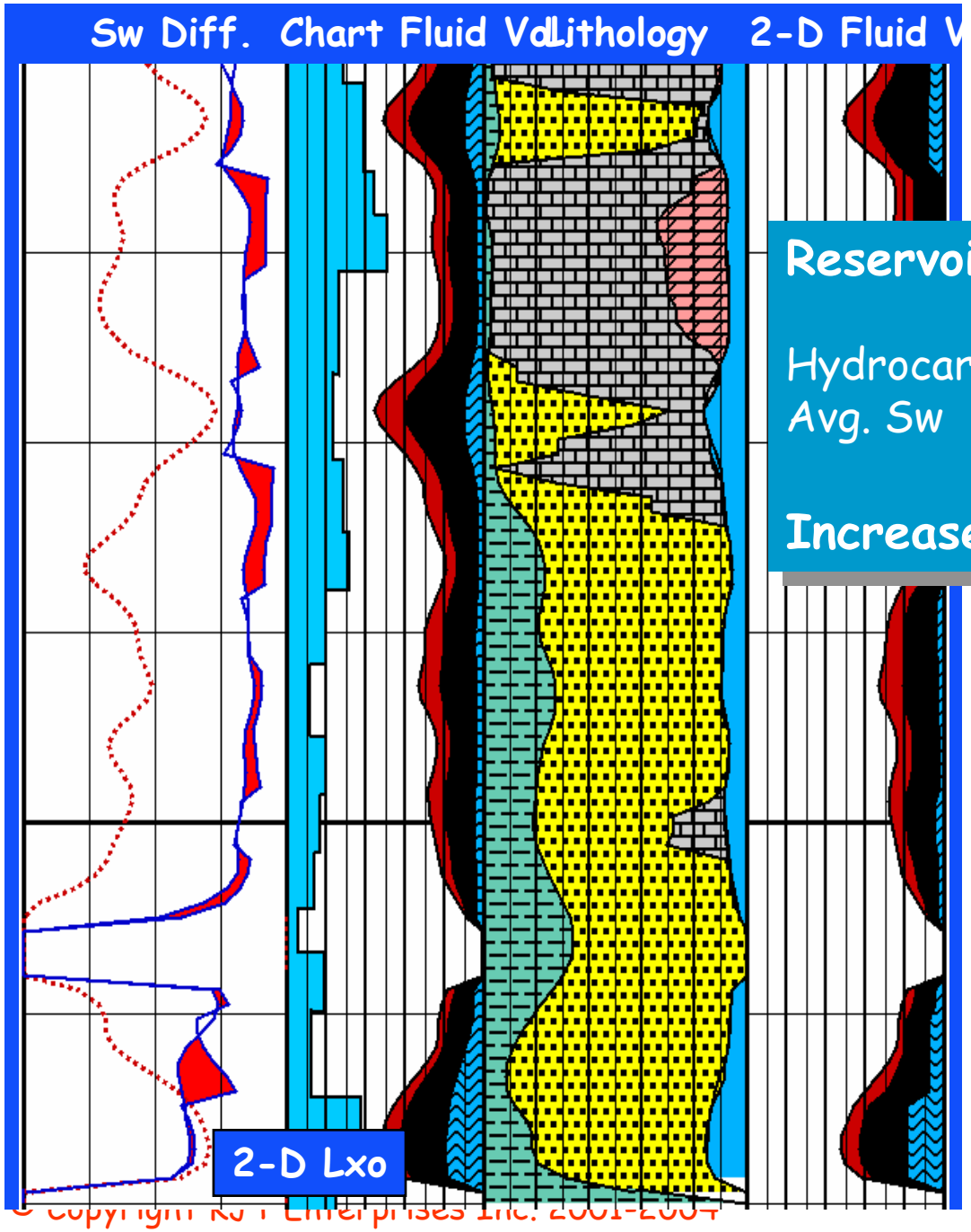


After Strack et al., 1998

DLL underestimating oil reserves



After Strack et al., 1998



Reservoir Analysis	Chart	2-D
Hydrocarbon Meters	5.4	6.0
Avg. Sw	25%	21%
Increased OIP Estimates		**10%**

2-D Inversion versus chart interpretation

After Strack et al., 1998

Inversion Conclusions:

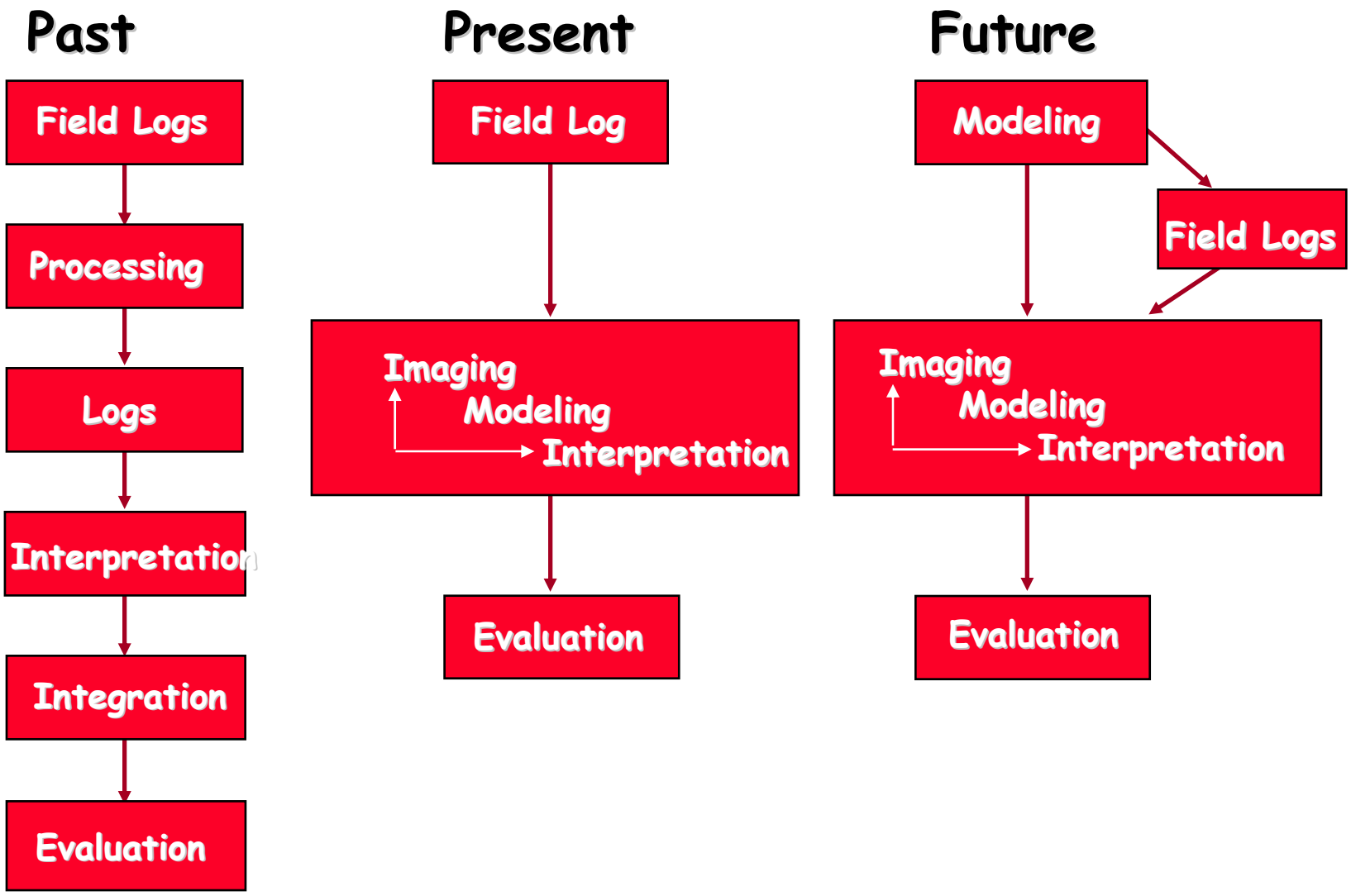
- Better delineated oil bearing zones
- More accurate formation parameters
- Risk analysis parameters
- New ways for data integration & upscaling
- Frontier: horizontal well interpretation
- Future: Imaging

After Strack et al., 1998

Resistivity logging: Past, Present & Future

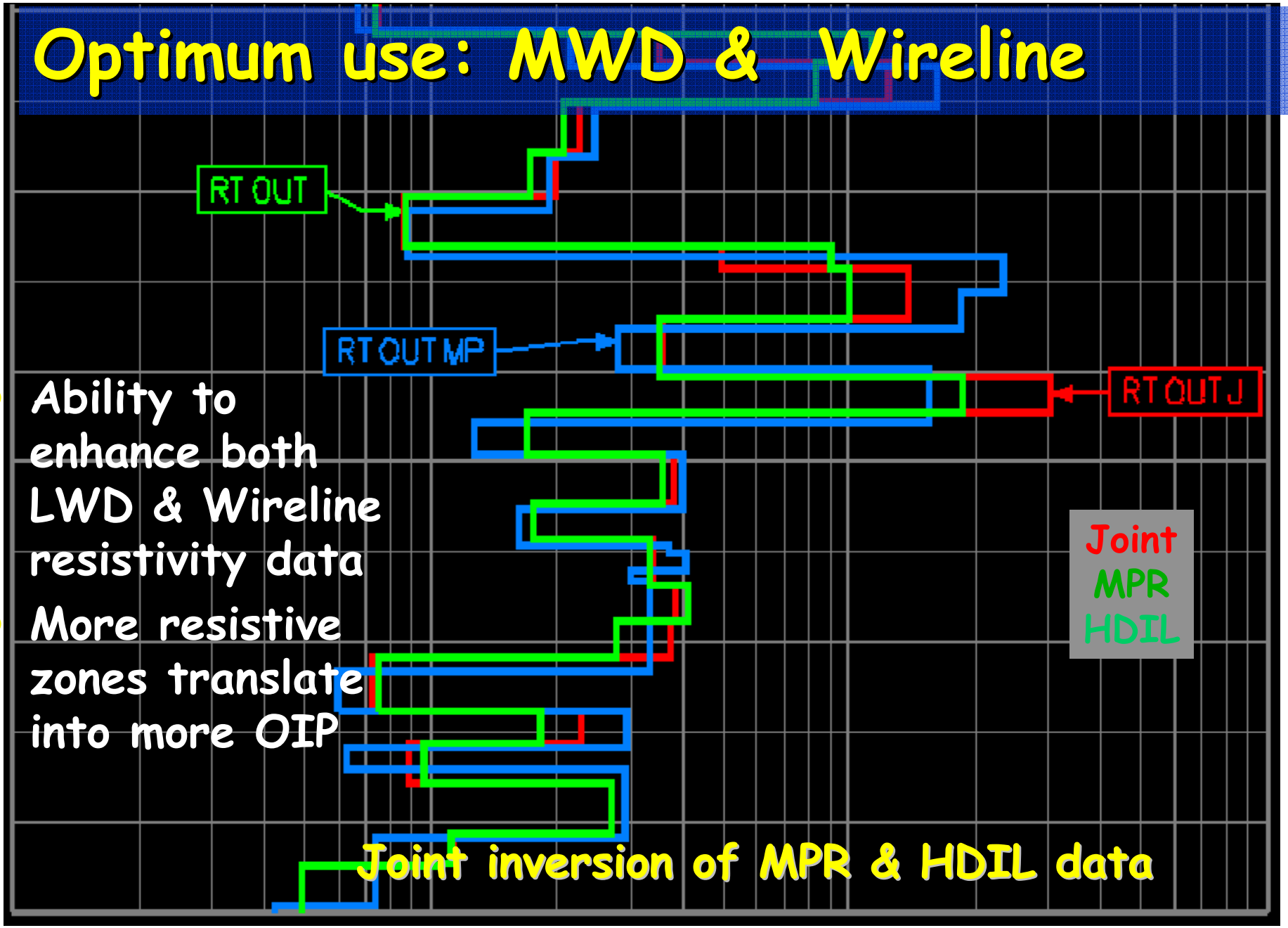
- Introduction
- Past
  - History
  - Older tools
  - Pitfalls
- Present
  - Overall concept
  - Improved tools
  - Innovative tools
  - Interpretation
- **Future**

The paradigm shift



After Strack et al., 1998

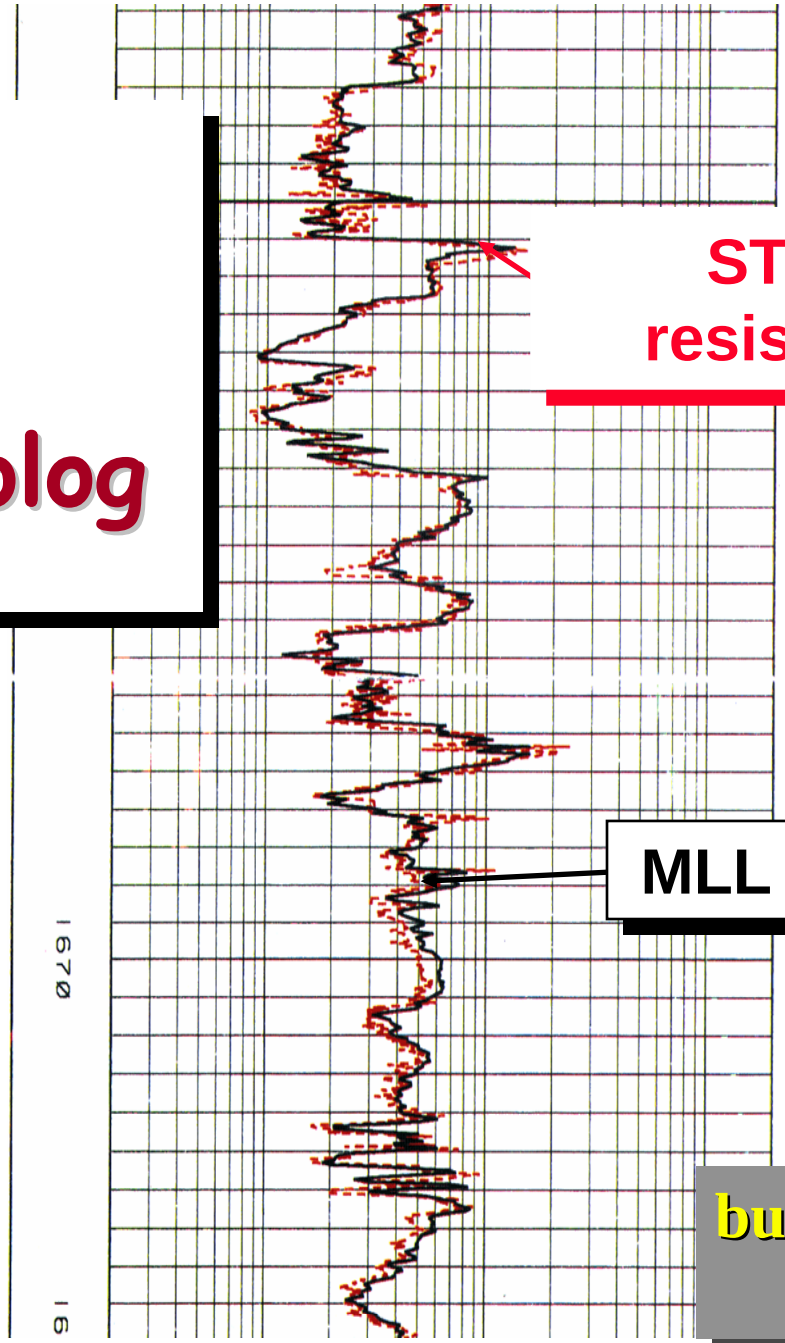
Optimum use: MWD & Wireline



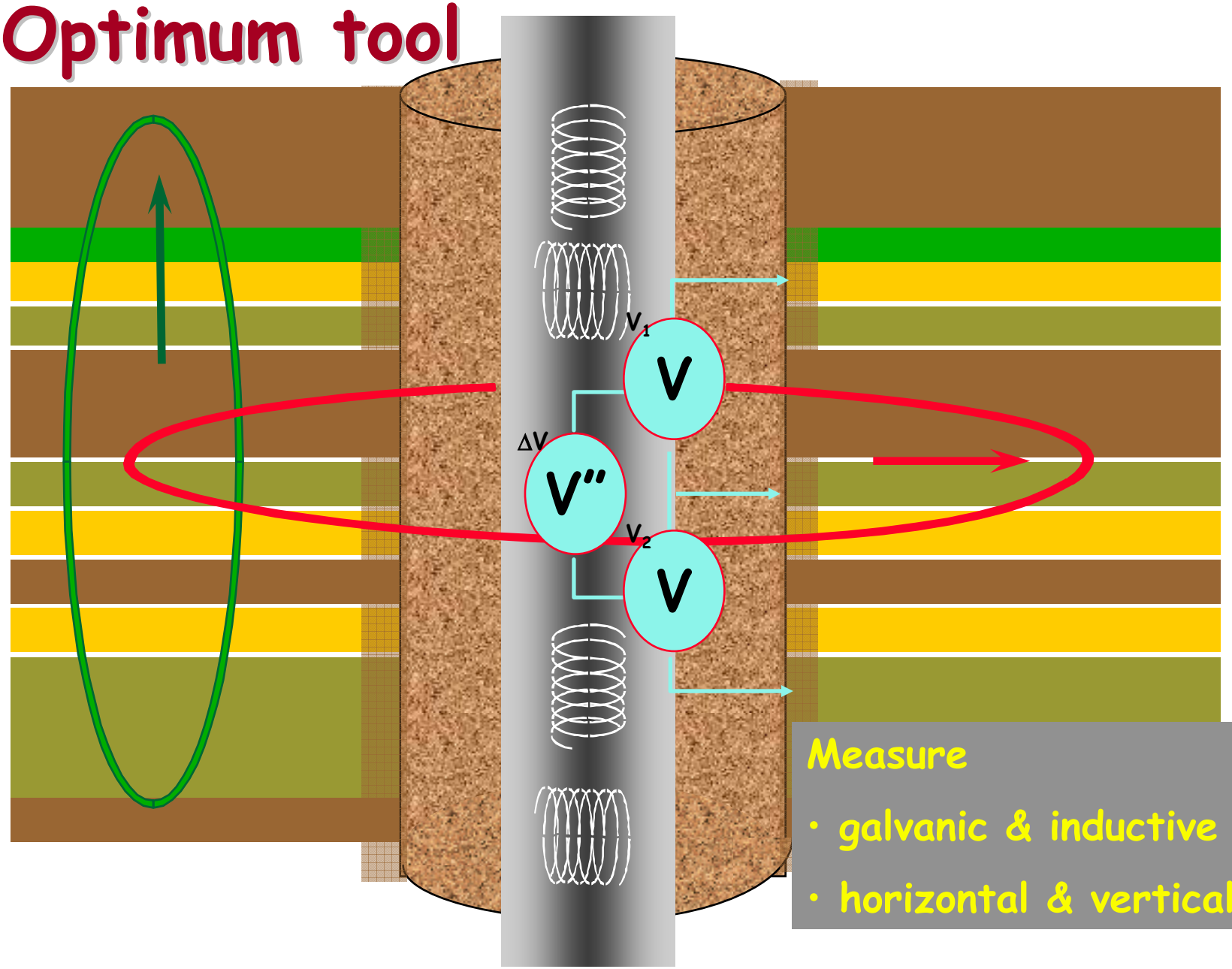
- Ability to enhance both LWD & Wireline resistivity data
- More resistive zones translate into more OIP

After Strack et al., 1998

Integrated Imager & Microlaterolog



Optimum tool



Measure

- galvanic & inductive
- horizontal & vertical

General formation evaluation trend

- Optimum use of MWD & wireline
  - MWD: routine and steering
  - wireline: imaging and deep (1-10 years then MWD)
- Advanced logs: mineralogy, downhole analysis..
- Downhole laboratories & factories
- Integrated optimized solutions

  - **tie with SWD to seismic cube**

KMS Technologies – KJT Enterprises Inc.
6420 Richmond Ave., Suite 610
Houston, Texas, 77057, USA
Tel: 713.532.8144

info@kmstechnologies.com

Please visit us
http://www.kmstechnologies.com//