How geo-detectives drive

Seismic Geo-Petro Normalisation

30 minute presentation: how to

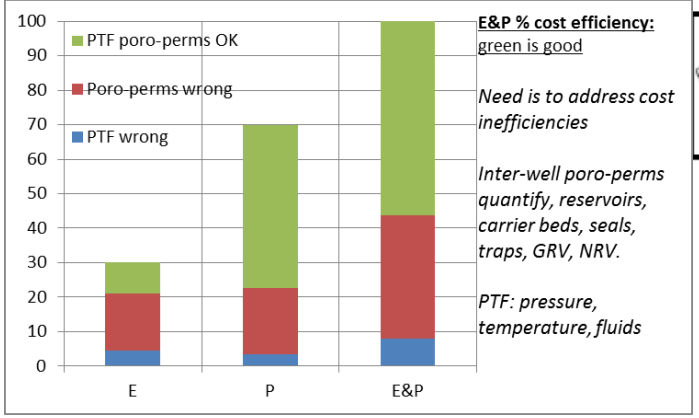
- Double geo- petro information in seismic.
- Cut in E&P cost & risk >10%, >$5/b to be saved.
- Drive quantitative interpretation

Rule based **E**xpert systems **IT**

Seismic interpretation: QI, shapes, attributes, geology, petrophysics.

- Ken Armitage learned his trade, mostly expatriate, in big oil companies, 1971 to date.
  - After 5 years, Met Police, he became a geo-detective.
    - 1st objective: prevent wasted E&P investment.
    - 2nd objective: arrest causes of E&P waste, as they are defined.
- With data from ‘000’s of E&P projects (before & after cost), he used well & seismic data to define geo- causes of wrong poro-perm forecast.
  - He made QI, quantitative interpretation, rules and tools double inter-well seismic, geophysical, and geological and Petrophysical data.
  - This should cut bad E&P cost & risk from 1/3rd to 1/4th.

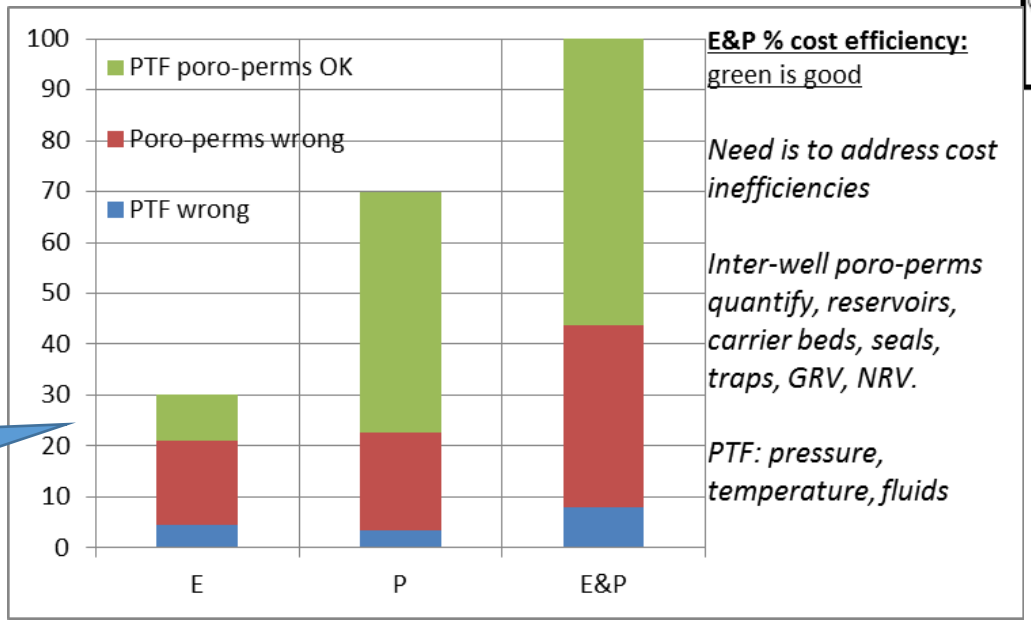
Problem addressed by GeoDirk



- E&P investment is constrained by
  - Low oil price & investors acting as if 'peak oil' is not imminent.
  - Low investor confidence, concerning E&P efficiency.
    - Rules & tools made for E&P of large, simple, conventional traps that are inefficient for E&P of remaining small, complex traps & shelf edges.
- 37.5% of E&P cost is wasted by poro-perm forecasts.
  - Poro-perm (holes & connection) mapping is risk dependent upon inter-well lithology mapping. We have to better quantify geology.
  - Exploration, ¼ of E&P cost; ¾ of this- wrong inter-well poro-perms.
  - Production, ¾ of E&P cost; ¼ of this- wrong inter-well poro-perms.
- E&P managers and investors need evidence that
  - We can double & integrate inter-well geo- petro information
  - Doubled G&G resolution makes E&P 15% more efficient.
  - Soon, supply and demand will sustain higher oil price.
  - Increased E&P funding is economically appropriate, now.

Cost Analysis

E&P spends $50/b x 100Mb p.d. $5B per day.

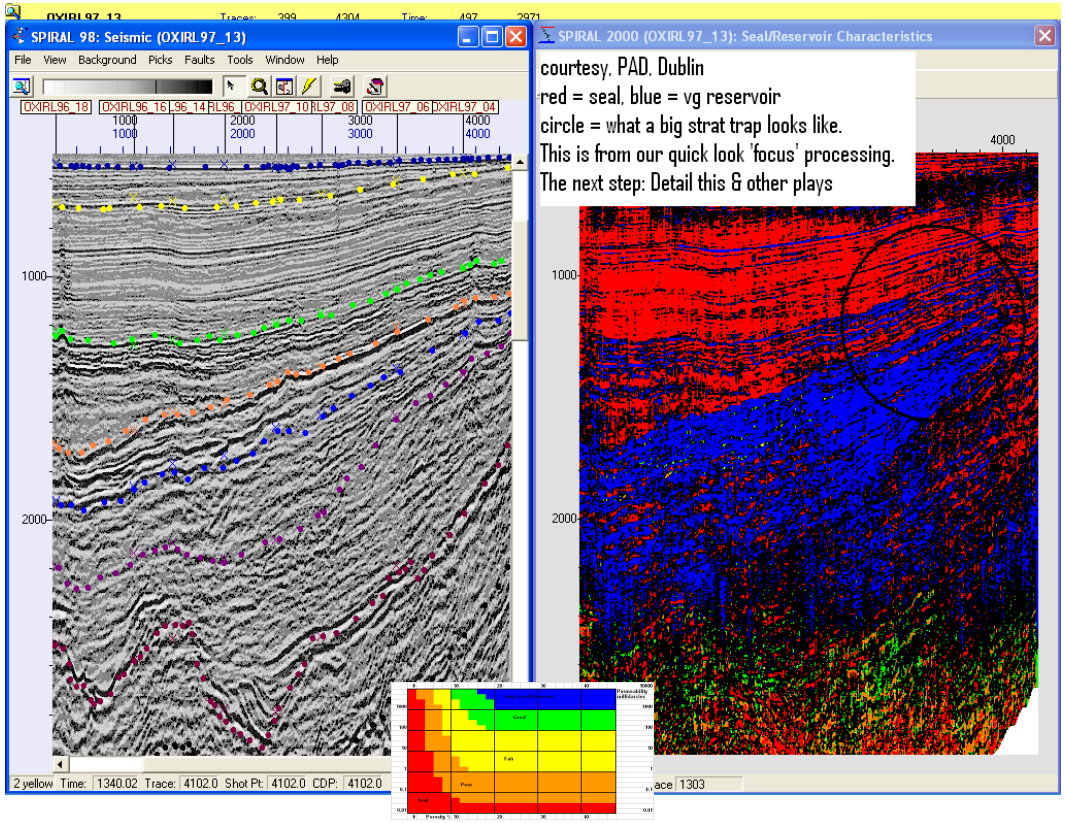


Per $100 spent in E&P, >$35 generates no value, **by errors forecasting inter-well poro-perms** (i.e. risk dependent on lithology, as velocity is already low risk). This equates to $1.75B per day. Geo-normalisation relatively doubles inter-well data, at 12.5m3m, irrespective of field size.

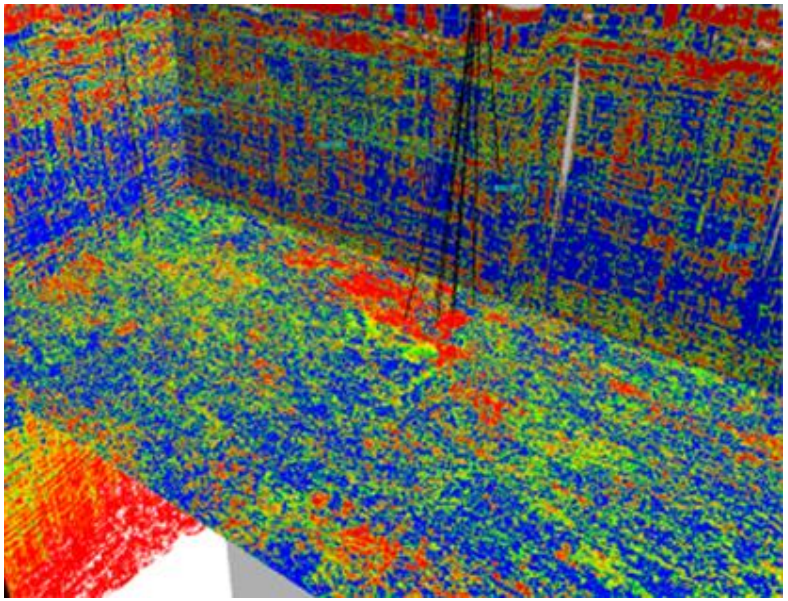
Oil companies should be able to convert $15 of this >$35 wasted cost, per $100, to value. This equates to $0.75B per day. This allows more than adequate margins for E&P staff to use rules and tools necessary to deliver this cost benefit.

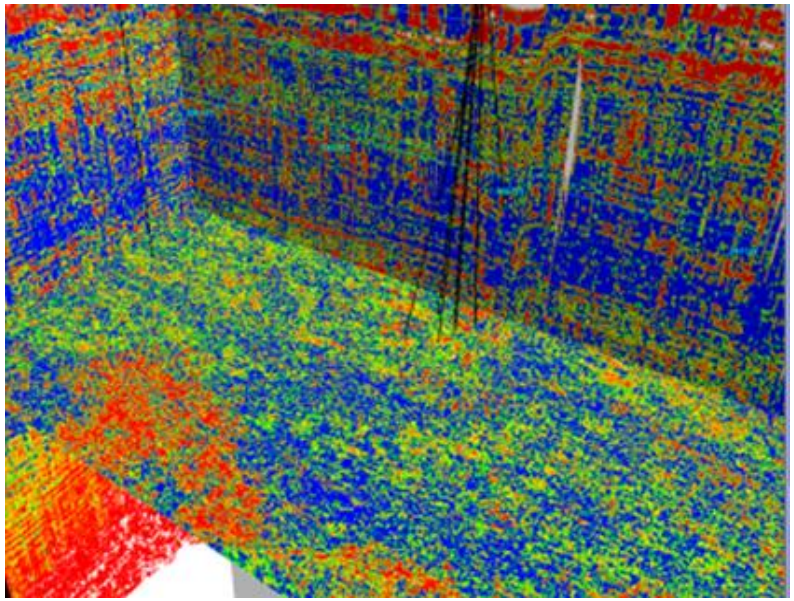
GeoDirk IOM Ltd offers to serve a 1st user group of 5, each committing 3 projects p.a. at £50k. The group then fine tunes existing Dbases, algorithms, apps, to enhance 1st user advantage.

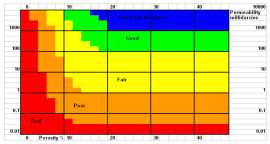
Key deliverables include Poro-Perm processing: seal- red, good reservoir- blue
Processing Resolution: 1/3rd of a wavelength



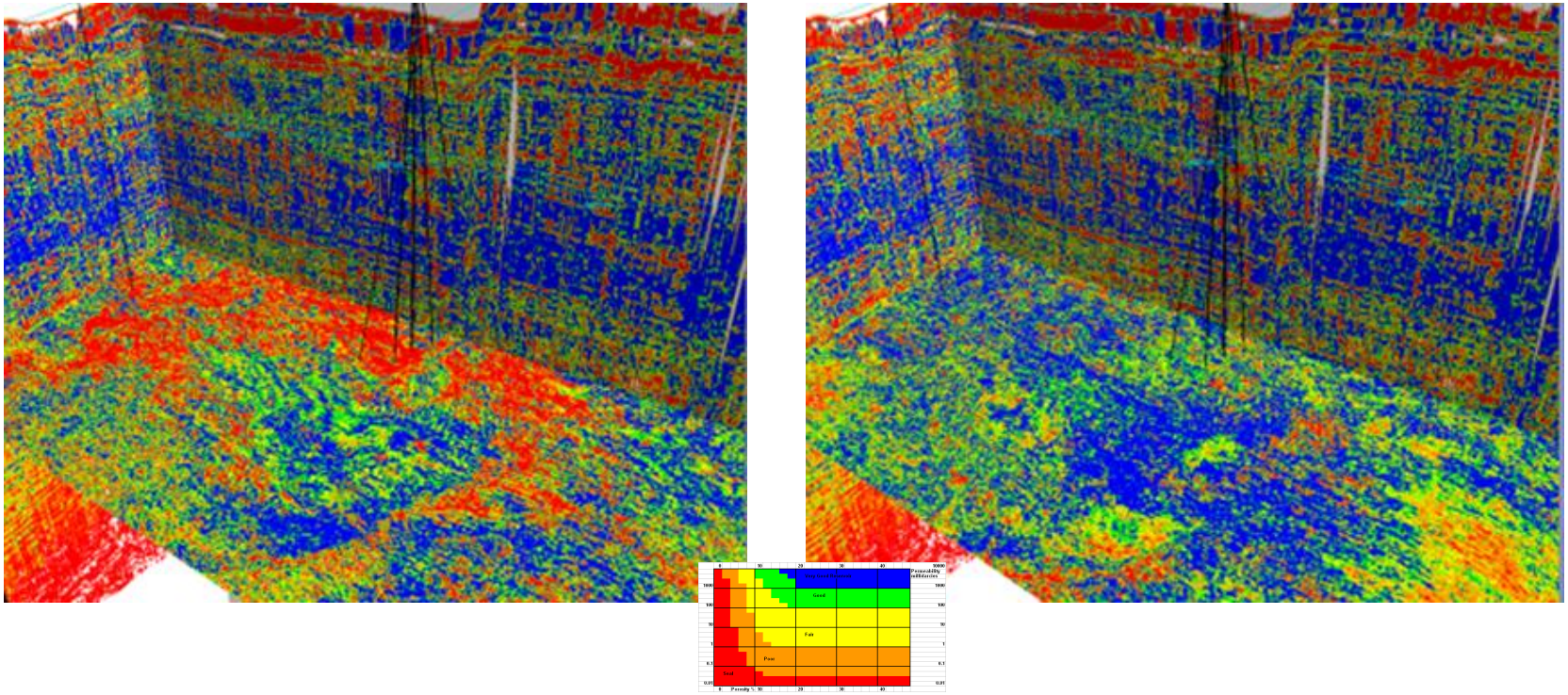
Seals (left) above Reservoirs (right) inter beds 1



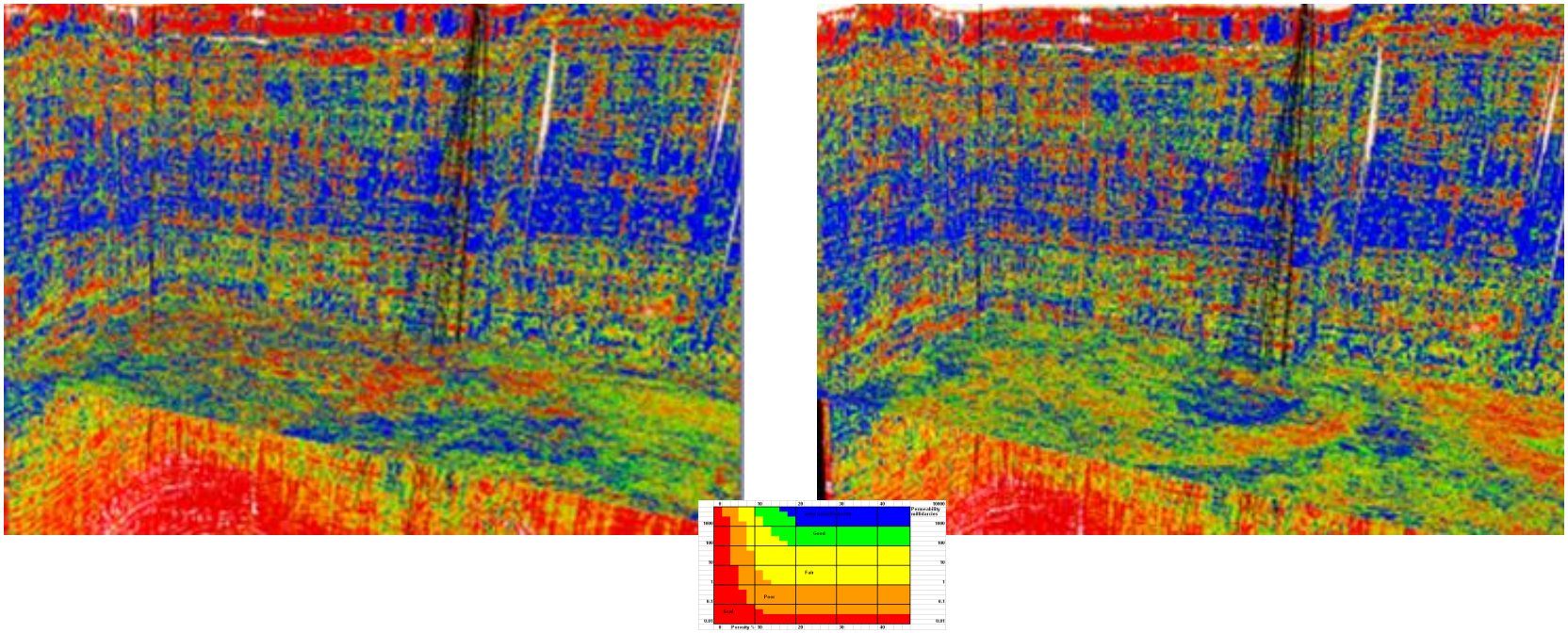




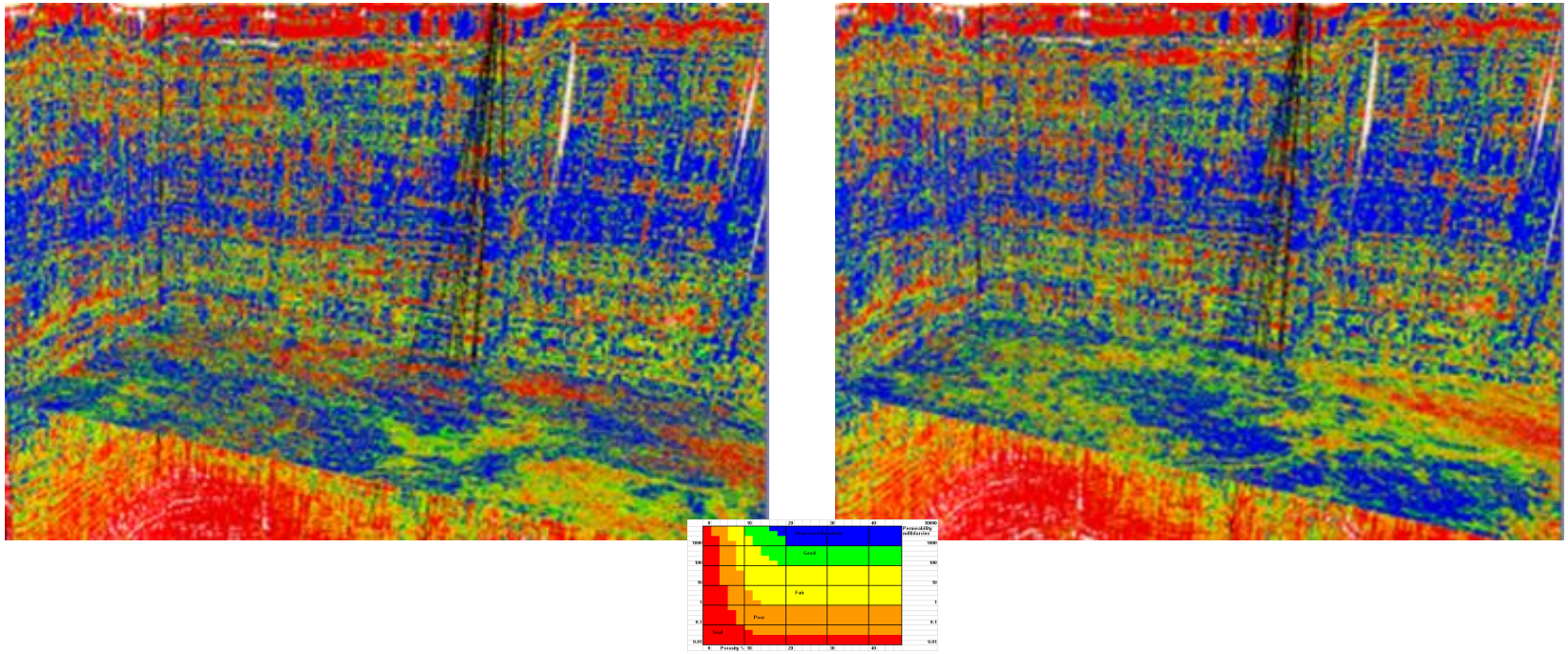
Seals (left) Reservoirs (right) inter beds 2



Seals (left) Reservoirs (right) inter beds 3



Seals (left) Reservoirs (right) inter beds 4



Action Plan

- North Sea has scores of oil or gas source kitchens
  - Each has >5BBoe, in mostly tight shale or mudstone
    - Usually close to platforms producing mostly water
- Can we find sweet spots/ unseen plays to extend field life by decades?
  - One such volume (‘00’s of km3 @ 12.5m3) is worked as a full integration of seismic/ geology & petro-physics.
  - Work all such volumes, & North Sea production should be extended at lower cost & risk
- Cut to Pres 2 example

Overview

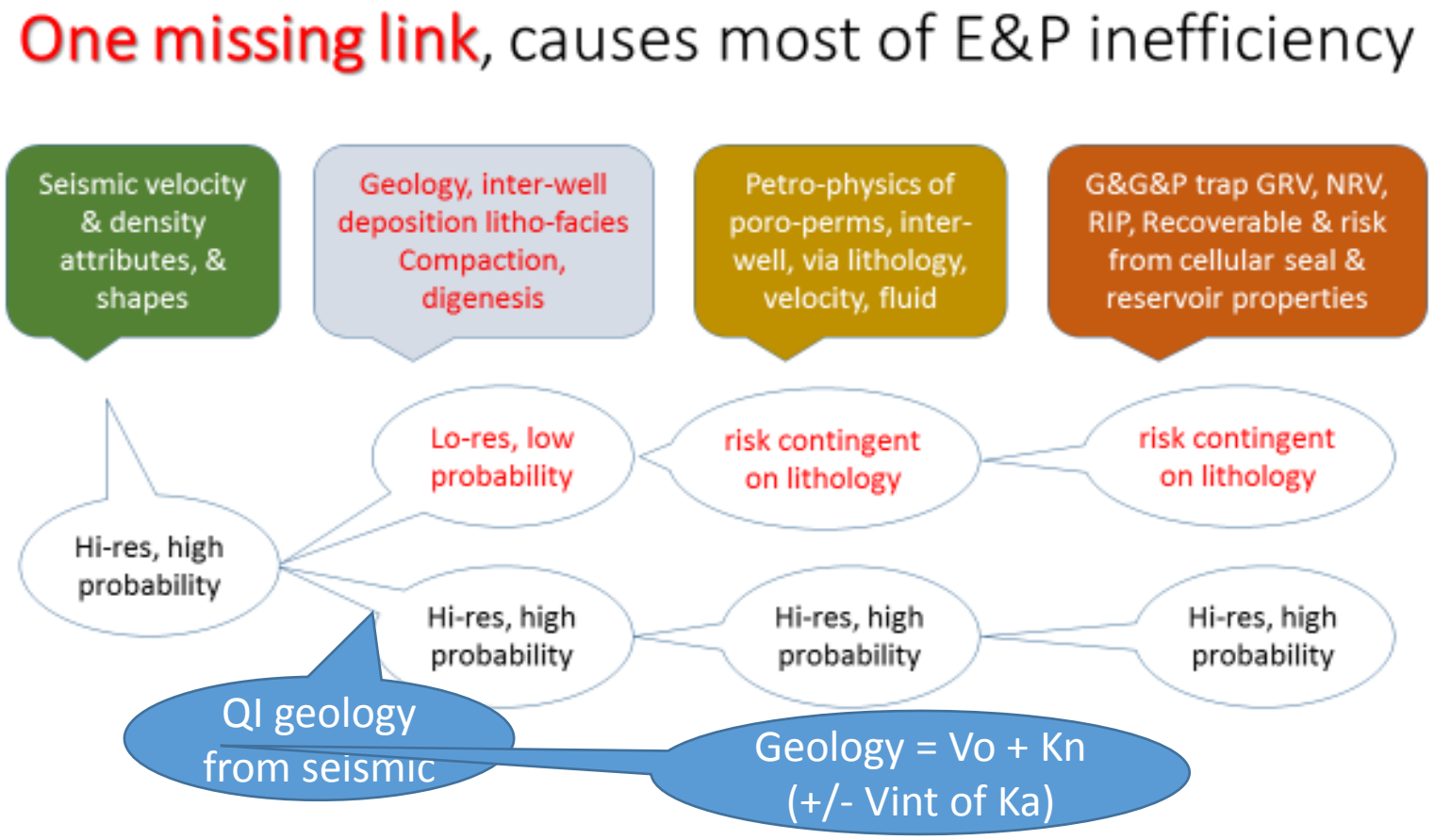
- If all sediments compacted similarly, then poro-perms would be mapped at much less risk, since
  - Time, velocity and depth are quantifiable with low risk.
  - Lithology (with few exceptions) is a low risk function of depth & velocity
  - Poro-perms are a low risk function of velocity & lithology.
- Geo-normalisation, (quantitative interpretation) uses
  - Data-bases of user defined 'normal depth' poro-perms, per lithology per velocity, in normal fluid pressure and temperature.
  - Means to separately define sequence volumes having similar burial/ digenesis controls, & any depth shift ΔD needed fit 'norm'. (Risks).
  - Means to process stacked 2-4D seismic samples (2 to 4ms) via spatial models of ΔD, AI changes to Vint to depth to lithology to poro-perms.
- You drive QI processing, from / to your workstation & add skills, fast.
- To double risk relevant information, thus probably save >$5/b, contact info @ www.geodirk or www.geoleum.
- 04/15: Scottish Enterprise puts GeoDirk on their 20 week 'Elevator' program, so we will set up, supported, their world class, sector leading, Aberdeenshire incubation hub.

What you get

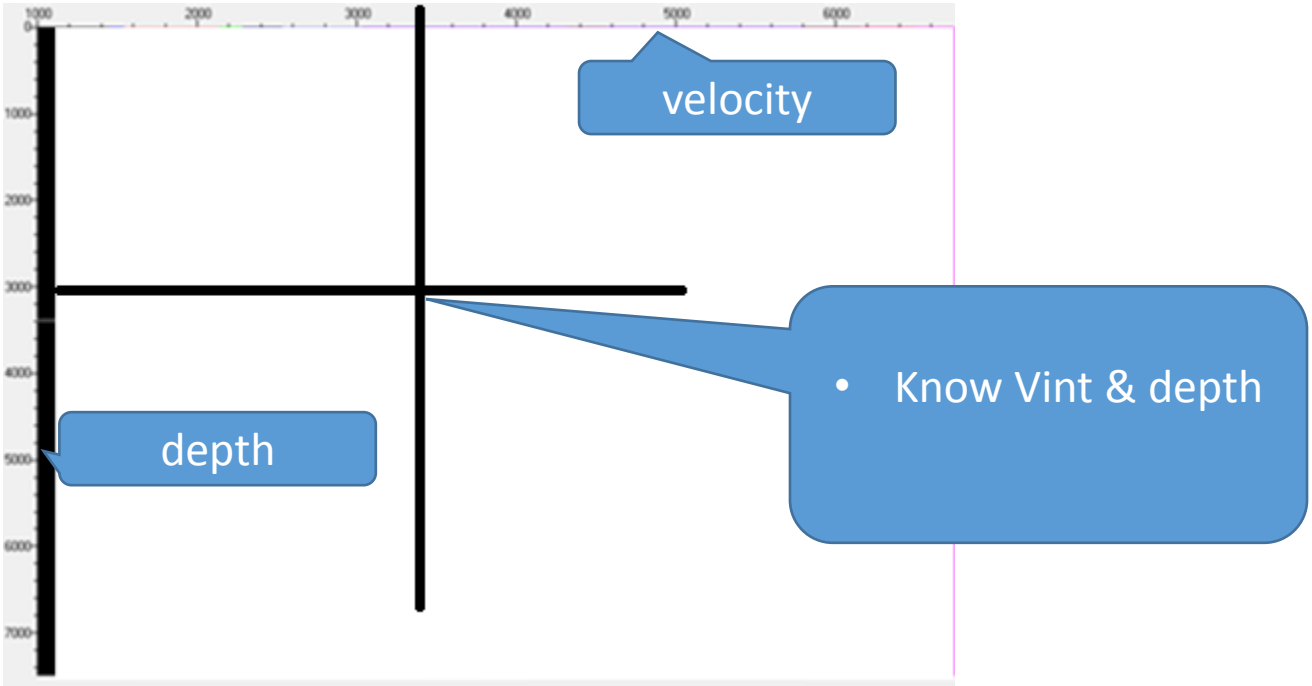
- Input
  - SEG-Y seismic, velocities, sequence boundaries +/- well data
- Deliverables to enter your workstations
  - Seismic SEG-Y files as velocity, lithology, local compaction, poro-perms, seal- reservoir parameters. Etc.
- Benefits, driven online, by client teams
  - Double inter-well, risk relevant data, at half the cost.
  - Cuts risk by around 15%, all sediment / structural types
  - Makes geology digital, to span seismic to Petrophysics.
  - Avoids problem that you get as many poro-perm models as the lithology models driving the processing, & most are wrong.
- Applications
  - Field development, near field, exploration, wildcat, 2-4D

The missing link

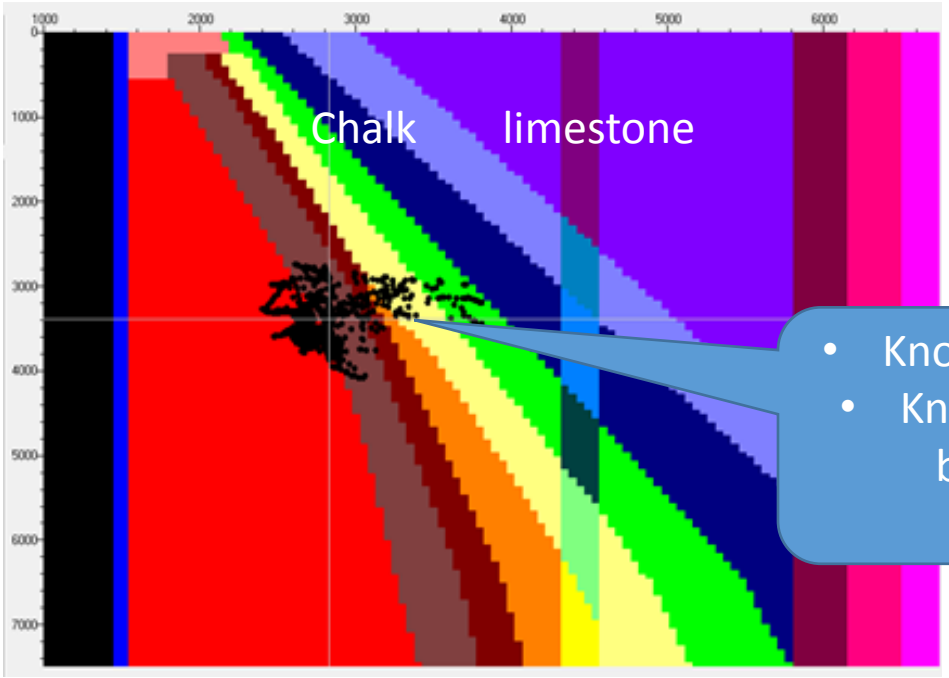
sensible poro-perms derive from sensible geology.



Geophysicists compute velocity & depth, any cell, 3D @ >98%, 2D @ >93% accuracy



In most prospective rock volume, compaction is similar, so lithology X-plots from velocity & depth.

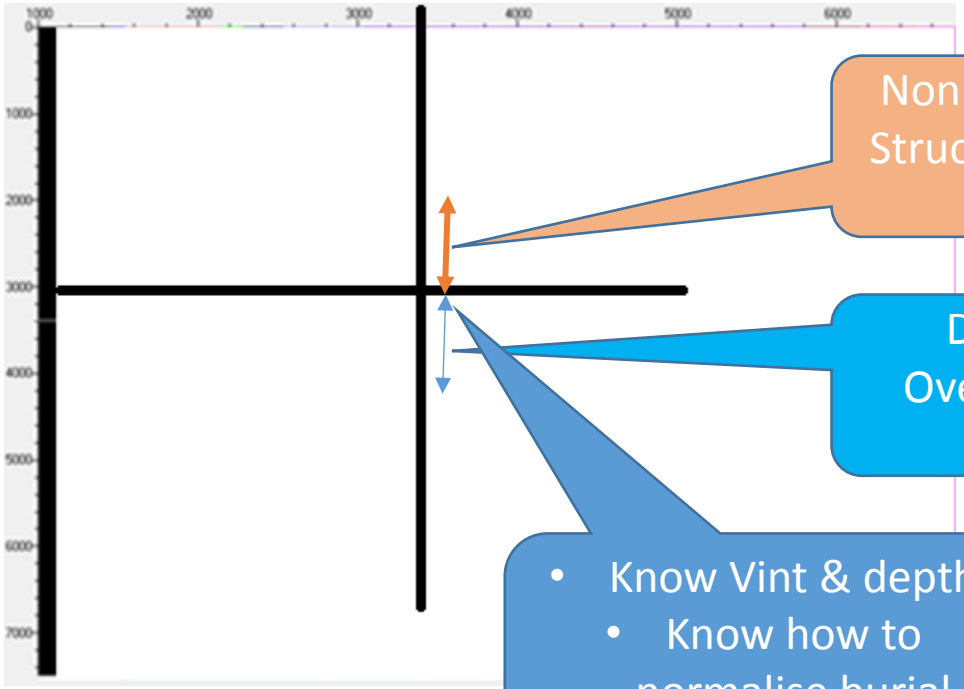


velocity

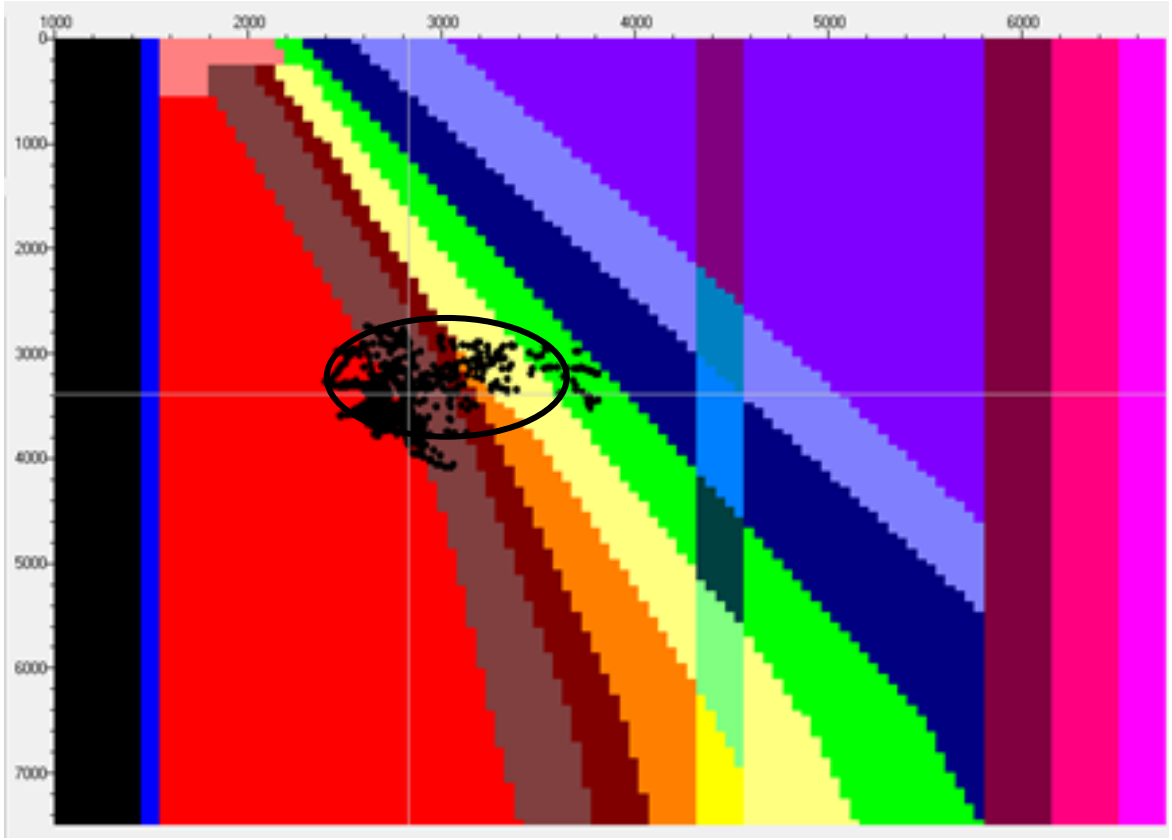
- Know Vint & depth
- Know lithology, if burial normal

Water, o/p shale, shale sand evaporites

Geo's must detect, per rock volume, if it compacted normally, or < or > than normal



Define/ lithology, normal burial in Velocity / depth domain.
Define associated porosities & permeabilities.
Then, quantify depth shift up or down to adjust local rock volumes to normal.

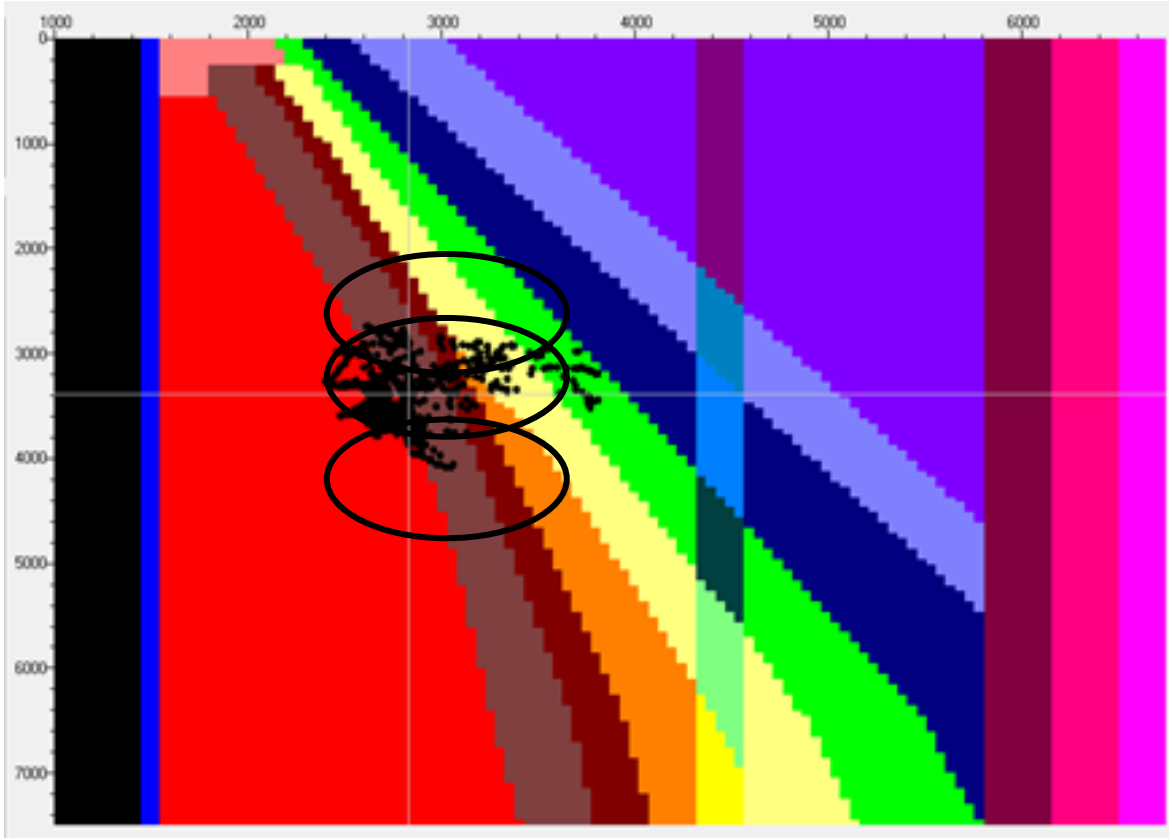


The centre sequence looks like spanning inter-bedded o/p shale to sand to carb rich clastic.

Where compaction occurs like this, any point on the chart can be defined by a velocity Vo + K line & depth

Shale compacts slower than sand which compacts slower than chalk.
Salt, evaporates don't compact (K is 0m/s/m)

Define/ lithology, normal burial in Velocity / depth domain.
Define associated porosities & permeabilities.
Then, quantify depth shift up or down to adjust local rock volumes to normal.

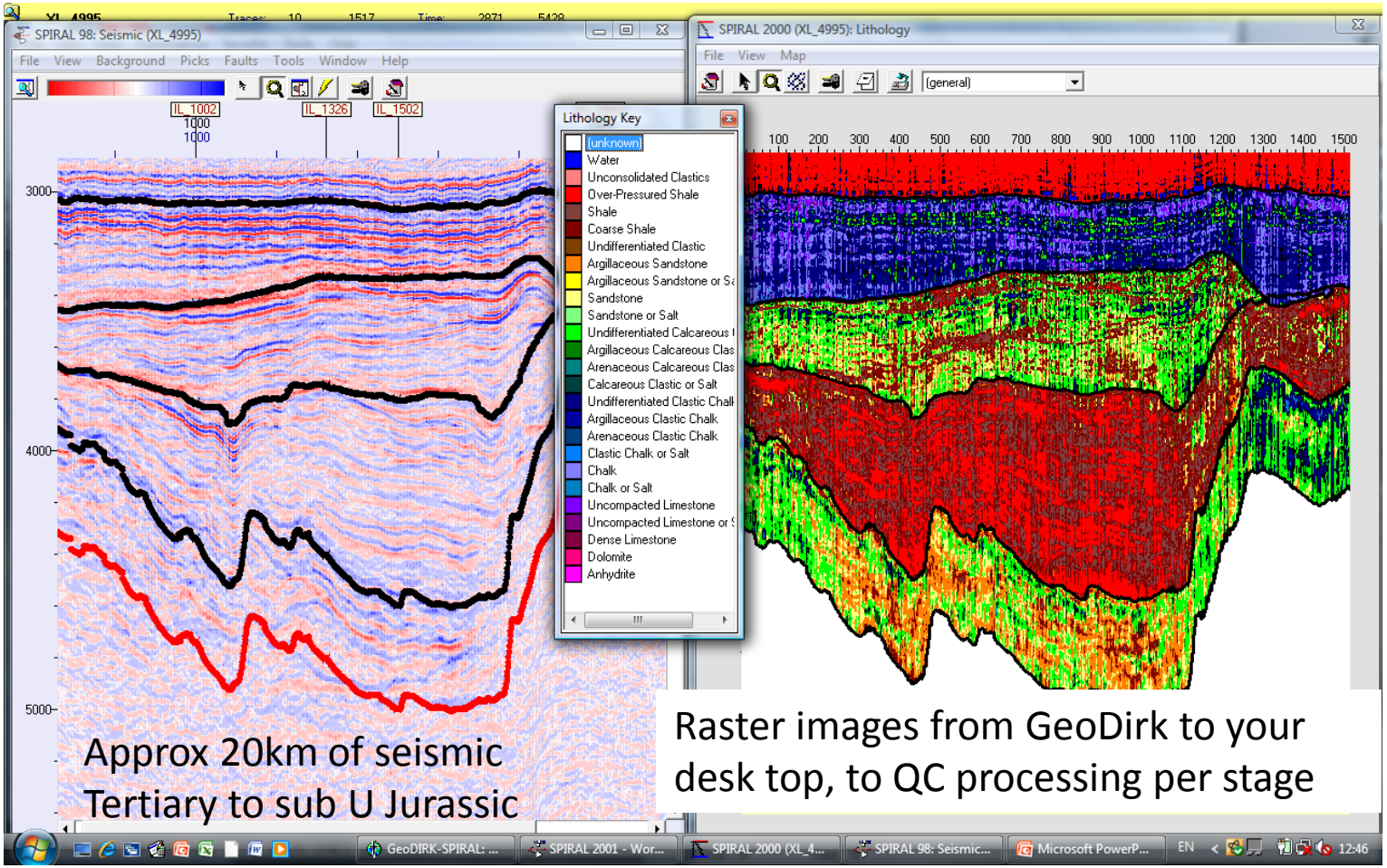


If normalisation shift is down, (adjusting for inversion, non vertical stress etc), the lithologies change (finer clastic).

If normalisation shift is up, (adjusting for deep water, o/p, slope vectoring etc), the lithologies change (coarser clastic)

Any point on the chart can be defined by a velocity Vo + K (+/- depth shift of KA, abnormal compaction) & present depth

Your ‘normal burial D-base’ & QI of ΔD all sequence cells, allow trace sample conversion to lithology. We’ll come to that.
If it looks sensible, it probably is. If not, find out why & amend.



Key tools, algorithms etc to drive ‘seismic geo-petro normalisation’

- Dbase 1, velocity domain: per lithology,
  - Porosity & permeability per fluid. Most companies already have this.
- Dbase 2, depth domain: normal shelf compaction
  - Per lithology, velocity, poro-perms per fluid.

Start projects with DBase2, holding all possible lithologies/ sequence. Don’t start with just local well data.

- App’s, DBases to work seismic shapes, attributes to separate volumes
  - Sharing similar compaction /digenesis in burial, / lithology
    - Normal +/- separate & net effects of water depth, non vertical stress/ strain, basin or salt inversion, o/pressure, faulting, igneous, mechanical strength, age, temperature, conductivity, etc.
  - App’s to define ΔD shift, local to normal burial depth / cell
- App’s to quantify / 2ms sample trace, normalised
  - AI, Vint, compaction Knormal, ΔD of Kabnormal by each risk,
    - & then net abnormal compaction / cell.
  - Then Lithology, porosity total, permeability,
  - Then seal, reservoir, carrier bed properties
  - Then seal base GRV, fluid substitution/ trap, gross & net rock volume

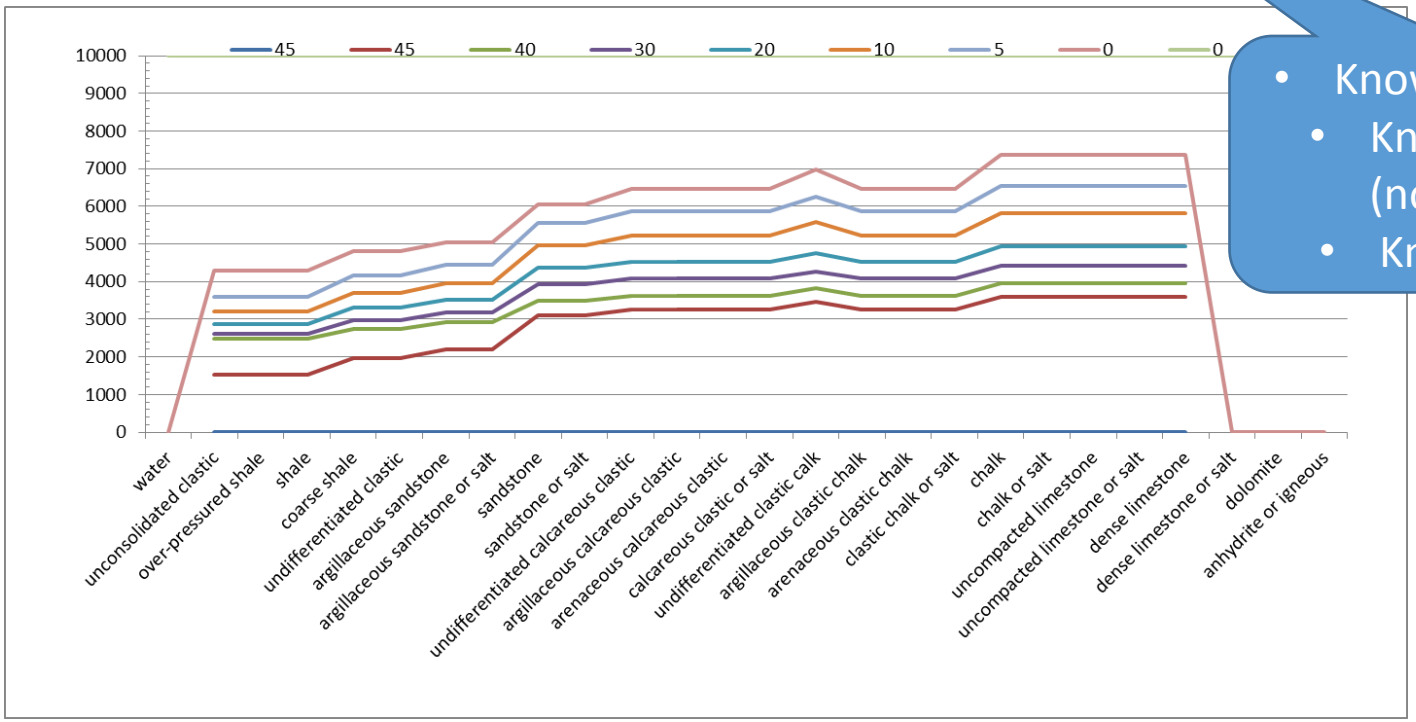
©	Burial Changes, re Normalisation
CONVA	*Conva: non vertical stress adjusted*
SINVA	*Sinva: structural inversion s/w adjusted*
BINVA	*Binva: structural inversion l/w adjusted*
FANVA	*Fanva: fault adjusted*
WANVA	*Wanva: water depth adjusted*
LINVA	*Linva: fluid adjusted*
PENVA	*Penva: pressure adjusted*
TENVA	*Tenva: temperature adjusted*
SHENVA	*shelf*
SLONVA	*slope*
ANVA	*Anva: age adjusted*
DENVA	*Denva: overburden density adjusted*
COLINVA	calibrated lithology normalised depth

Driving G&G&P seismic normalisation

- Pick all sequences in time
  - Relatively homogeneous litho units, separated by unconformities of correlated conformities.
  - Load well & seismic velocities, depth conversion 1
- Pick / sequence, well data: time, velocity, depth, poro-perms, fluids, pressure, temp, mechanical strength.
  - Define depth difference / sequence. to tie well data to generic normal compaction rock properties. Grid.
- Separate rock volumes with similar compaction /digenesis
  - Quantify normal +/- separate & net effects of water depth, non vertical stress/ strain, basin or salt inversion, o/pressure, faulting, igneous, mechanical strength, age, temperature, conductivity, etc.
  - Per rock volume of similar burial change causes, define ΔD to fit normal.
- Use this low frequency sequence geo- model to calibrate & drive G&G&P processing of trace data.
  - You spend a few weeks to integrate & double seismic geo- petro data. This should cut E&P cost & risk several %.

Velocity domain: porosity /lithology

- Picture of 30 lithologies in 15 groups, in brine & their porosity as a function of velocity.
- You tune this Dbase to fit your data.

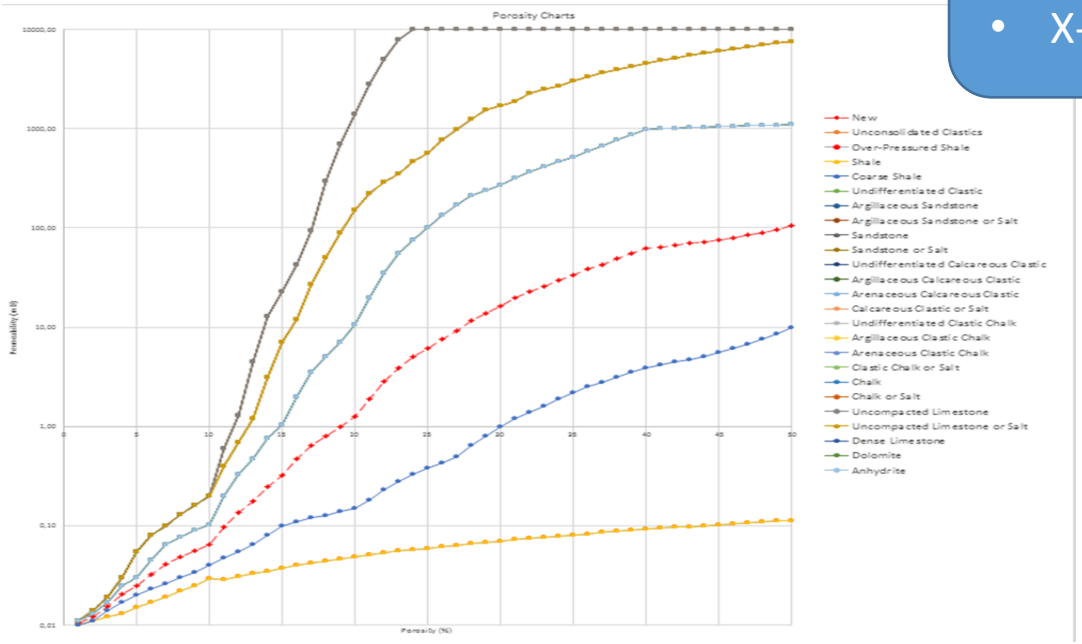


- Know Vint & depth
- Know Lithology (normalisation)
- Know porosity

Velocity domain: poro-perms /lithology

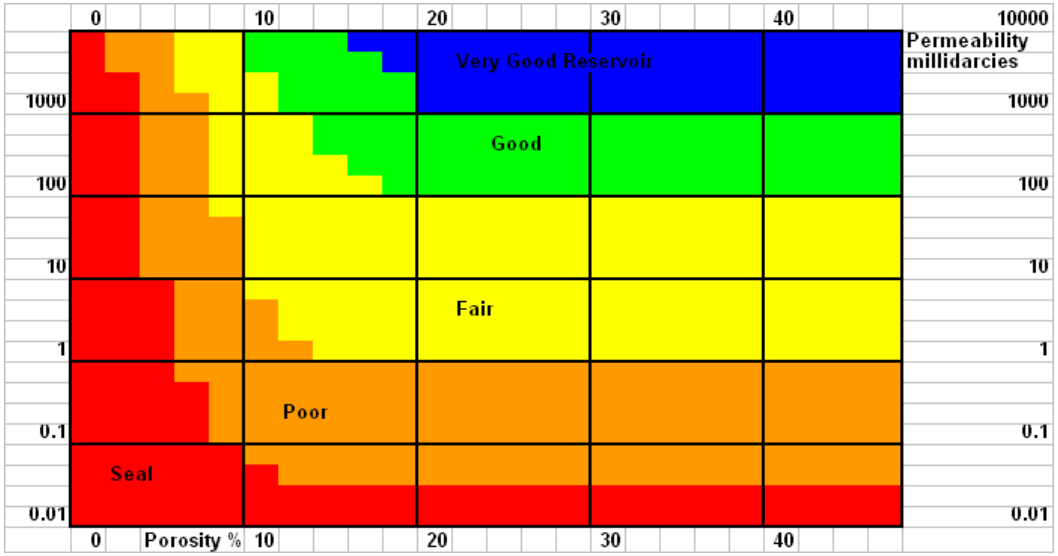
- Picture of 24 lithologies in 6 groups, in brine, and their porosity % X-plotted against log scale permeability
- You tune this Dbase to fit your data

- Know Vint & depth
- Know porosity
- X-plot permeability



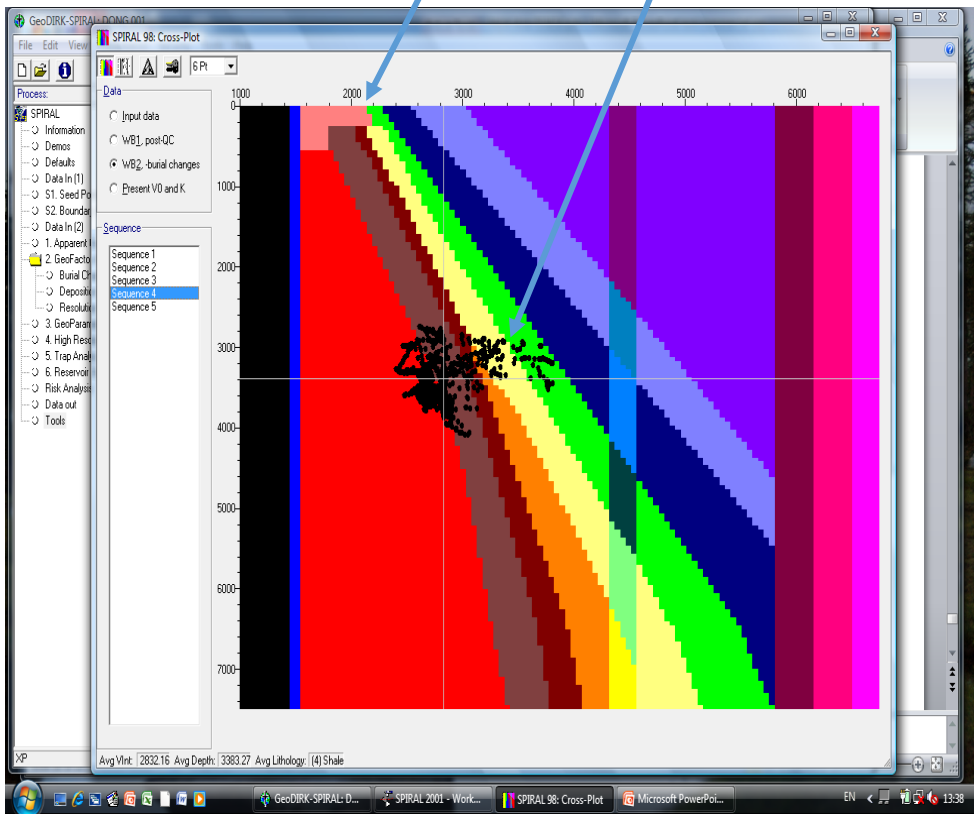
Velocity domain: poro-perms /lithology

- Picture of X-plot of porosity % and log permeability, coloured to show 5 groups guiding seismic display of seal, reservoir, carrier bed properties.
- You tune this Dbase to fit your data, to best display seismic poro-perms.



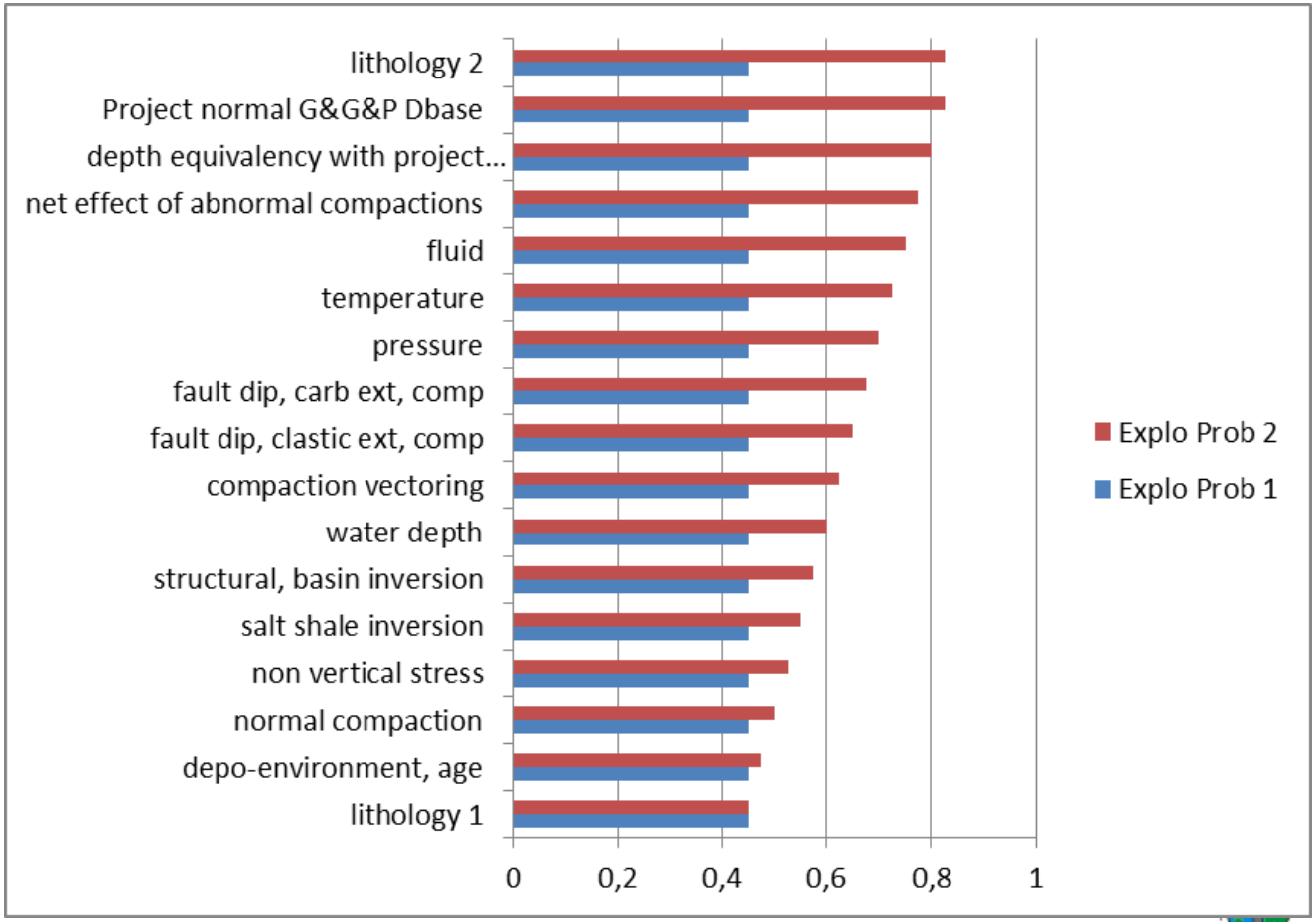
‘Normal compaction’, velocity, depth, lithologies. Vint = Vo + Kn

- Picture of Gardner’s type velocity horizontal/ depth vertical plot of key lithologies in brine
- Also various inter-bedded lithologies visible within one sequence rock volume sharing similar compaction.
- Red is o/p shale, brown shale, to yellow sand to blue carbonates etc.
- 4445 m/s could be salt.



Normalising rock volumes of similar compaction/ digenesis

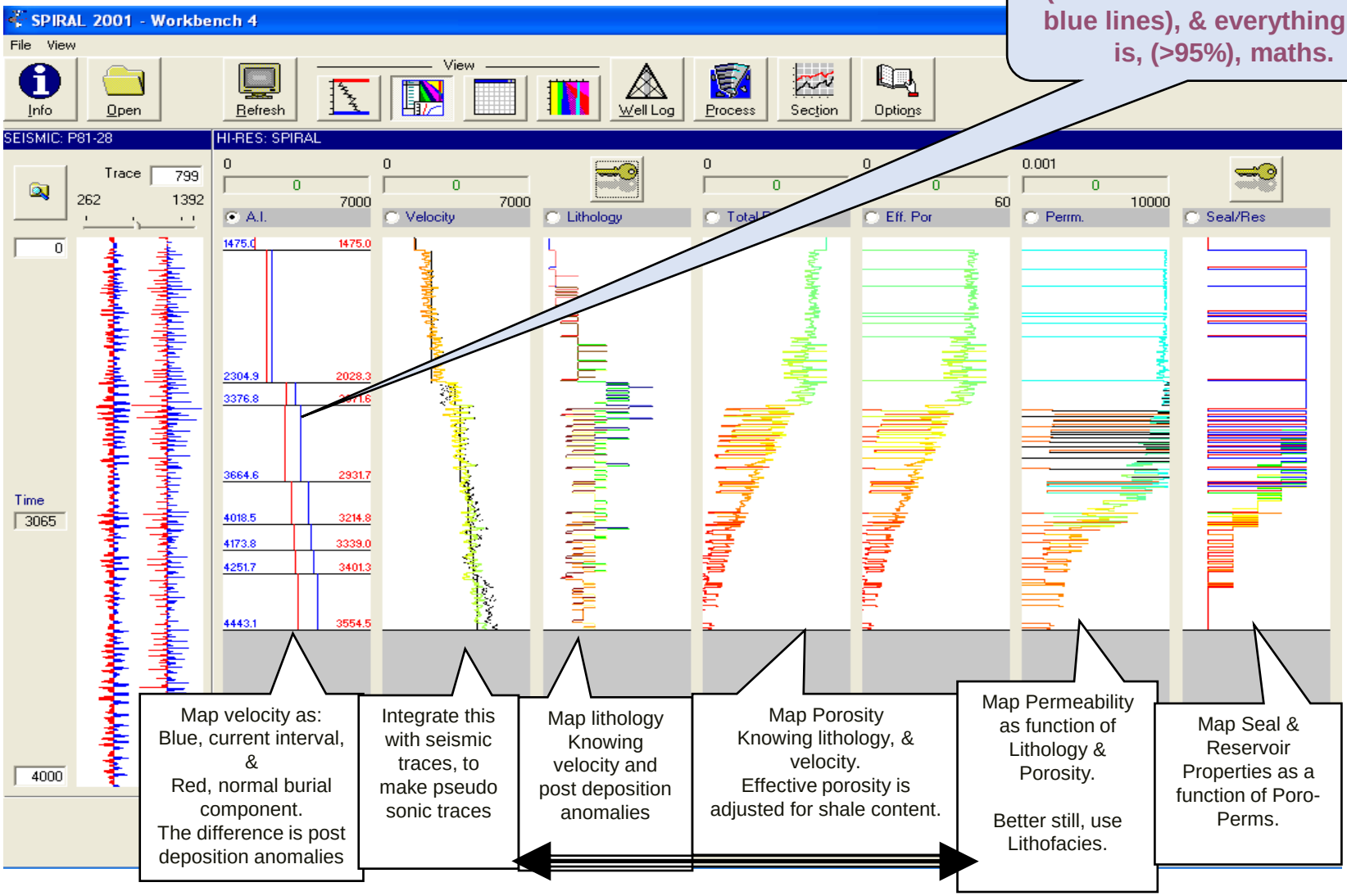
- Table of several geo-causes of non normal compaction with increasing depth, and programs providing QI of these risks.
- Algorithms & Dbases do the work



X disciplinary integration seismic rock properties by sequence & sample depth normalisation

geophysics	geology	petrophysics	Normal DBase
Vint, Density, shapes		Porosity from lithology & Vint	Inter-relate
Vo	lithology	Permeability from lithology & porosity	Lithology
KNormal	Normal for lithology	Seal base from poro-perms	Velocity Vint
Vint of KAbnormal	Local abnormal burial changes	Trap GRV sub seal from poro-perms	Depth
		Trap NRV after fluid substitution (extra burial change)	Poro-perms

Simple innovation.

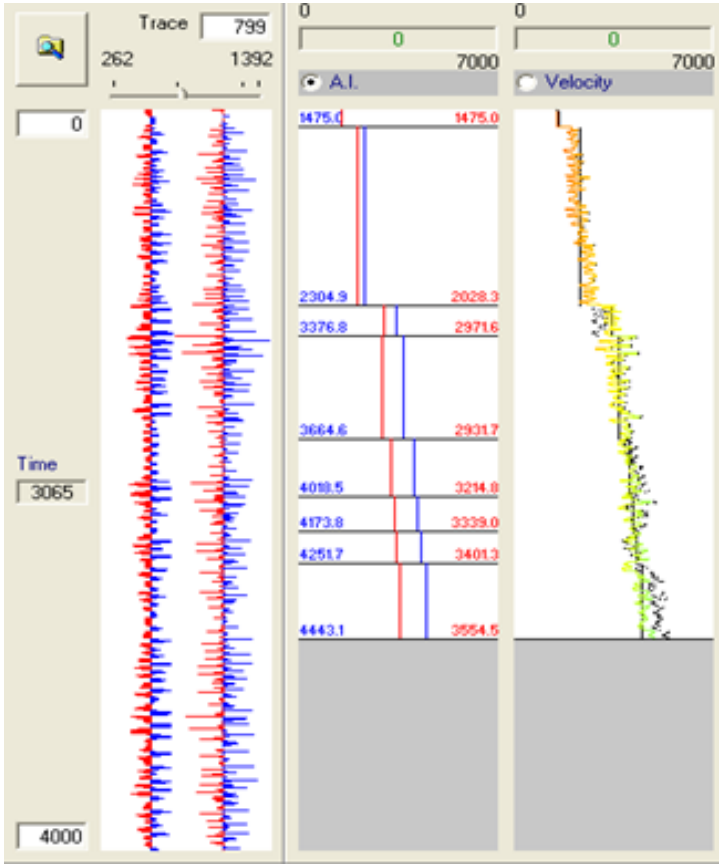


Porcupine, thanks to PAD & Spectrum

Seg-y seismic to velocity, for
a) depth conversion b) geo-petro normalisation

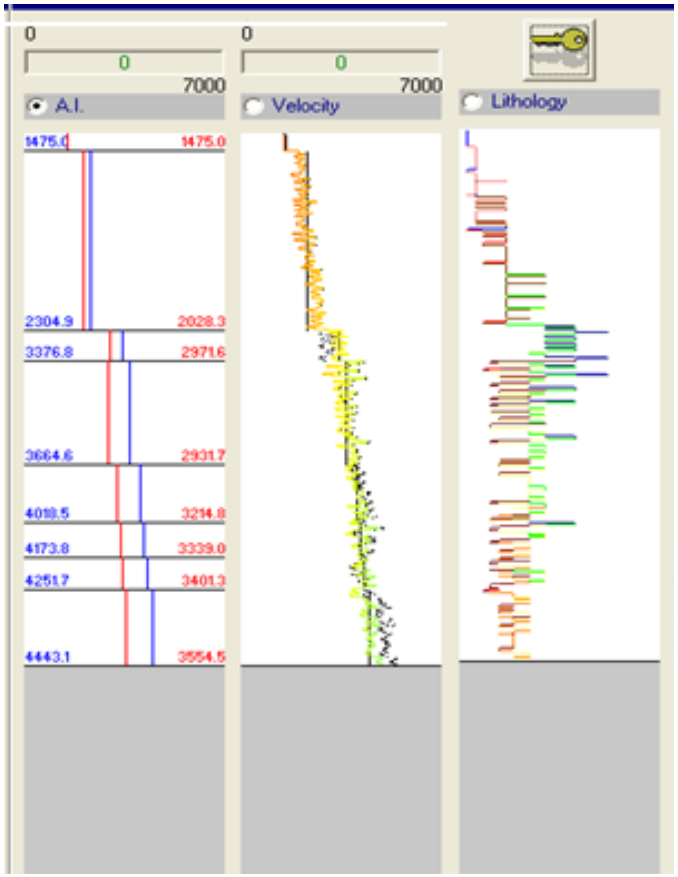
- Picture of trace samples integrated with low frequency sequence control, working AI changes from wavelet removal, then Vinterval.

- Picture of Vint shift for local KA abnormal compaction, based on average lithology mix and compaction rates.



Seismic to lithologies

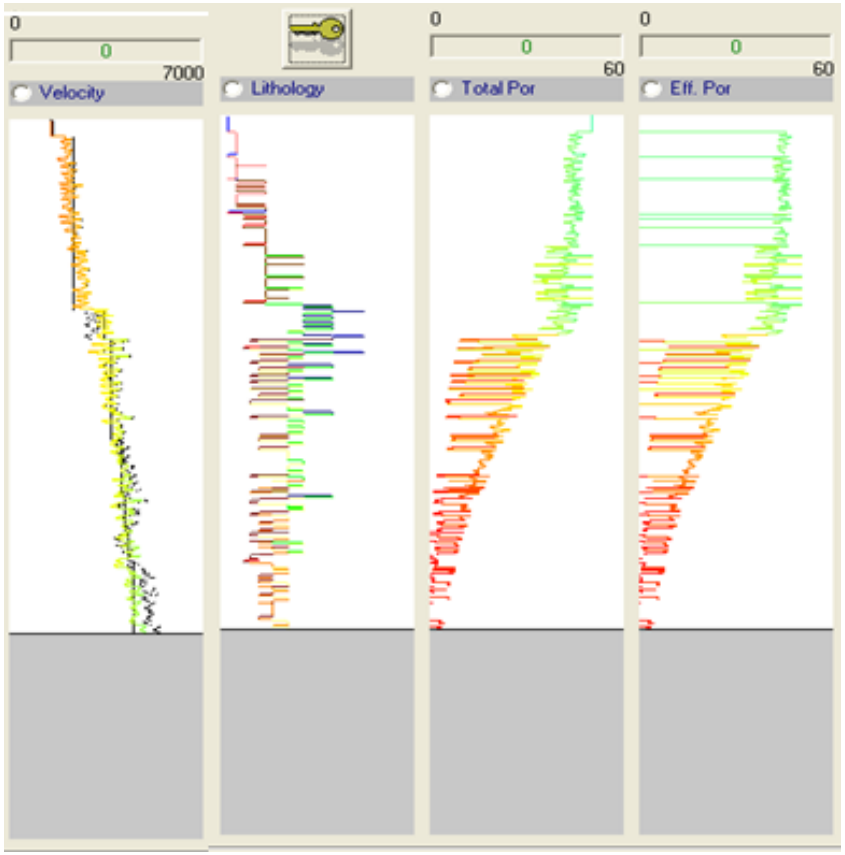
- Picture of trace conversion using Vo = VoN + KN +/- ΔD of Vint of KA
- Read lithology from sequence volume normalised to Gardner's type velocity/ depth plot



Velocity + lithology to porosity

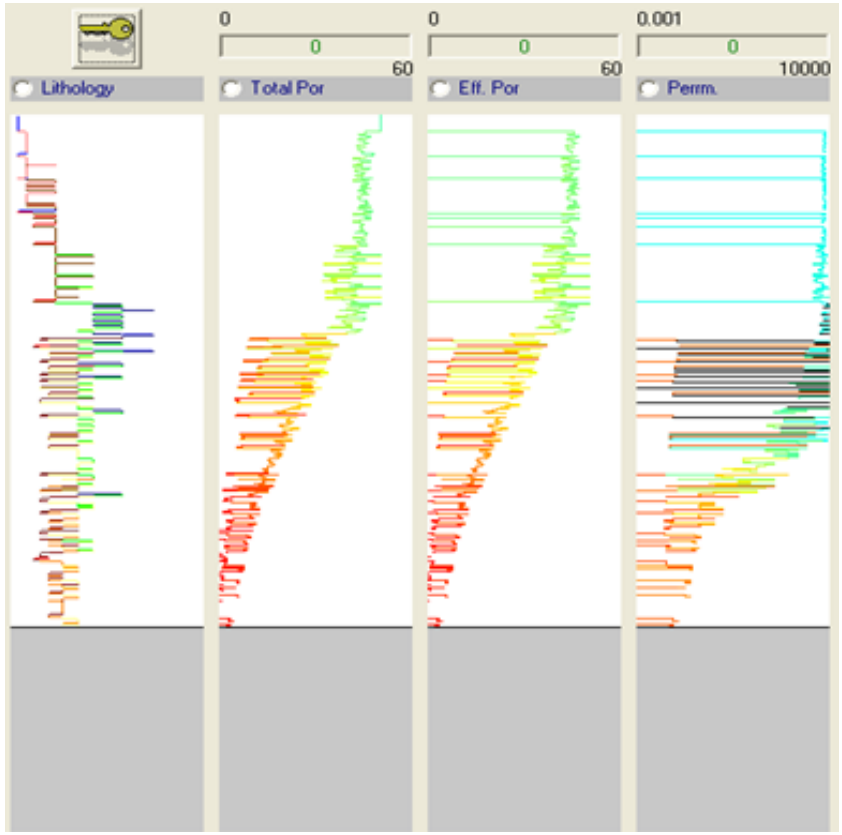
- Picture of Geo-normalised Vint & Lithology traces, converted to porosity, total (then effective using lithology's shale content).

- Use depth shift / sequence to equilibrate with normalised property Dbase



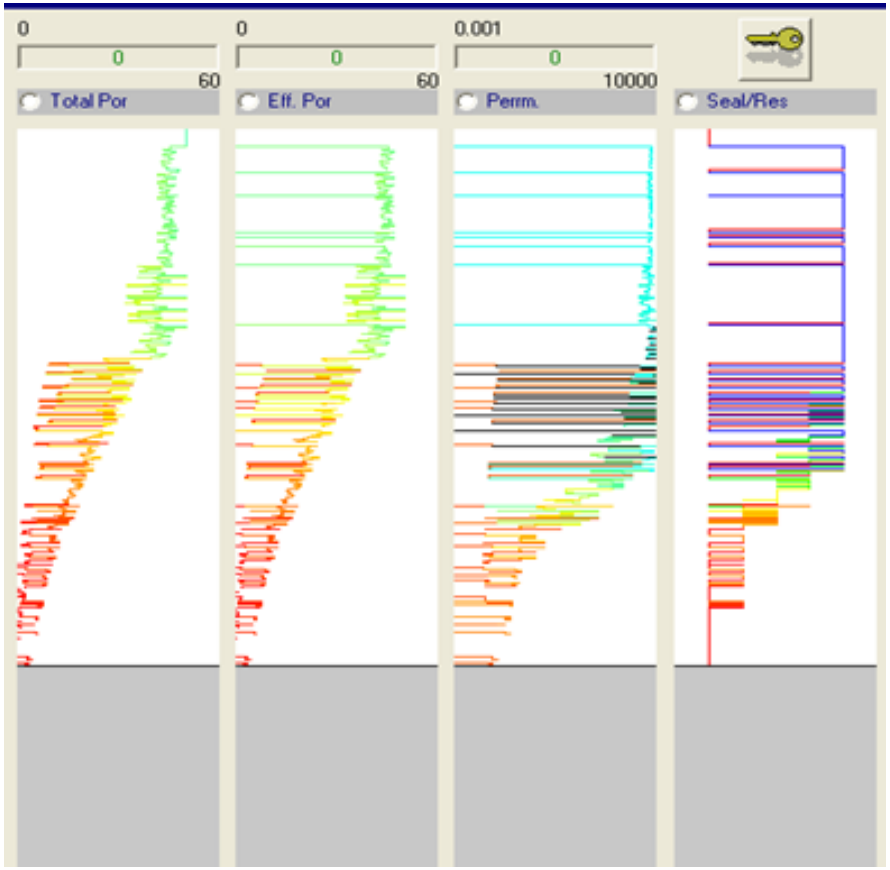
Lithology, porosity to permeability

- Picture of a traces permeability, via X-plot / sample of trace lithologies & total porosities
- Use depth shift / sequence to equilibrate with normalised property Dbase



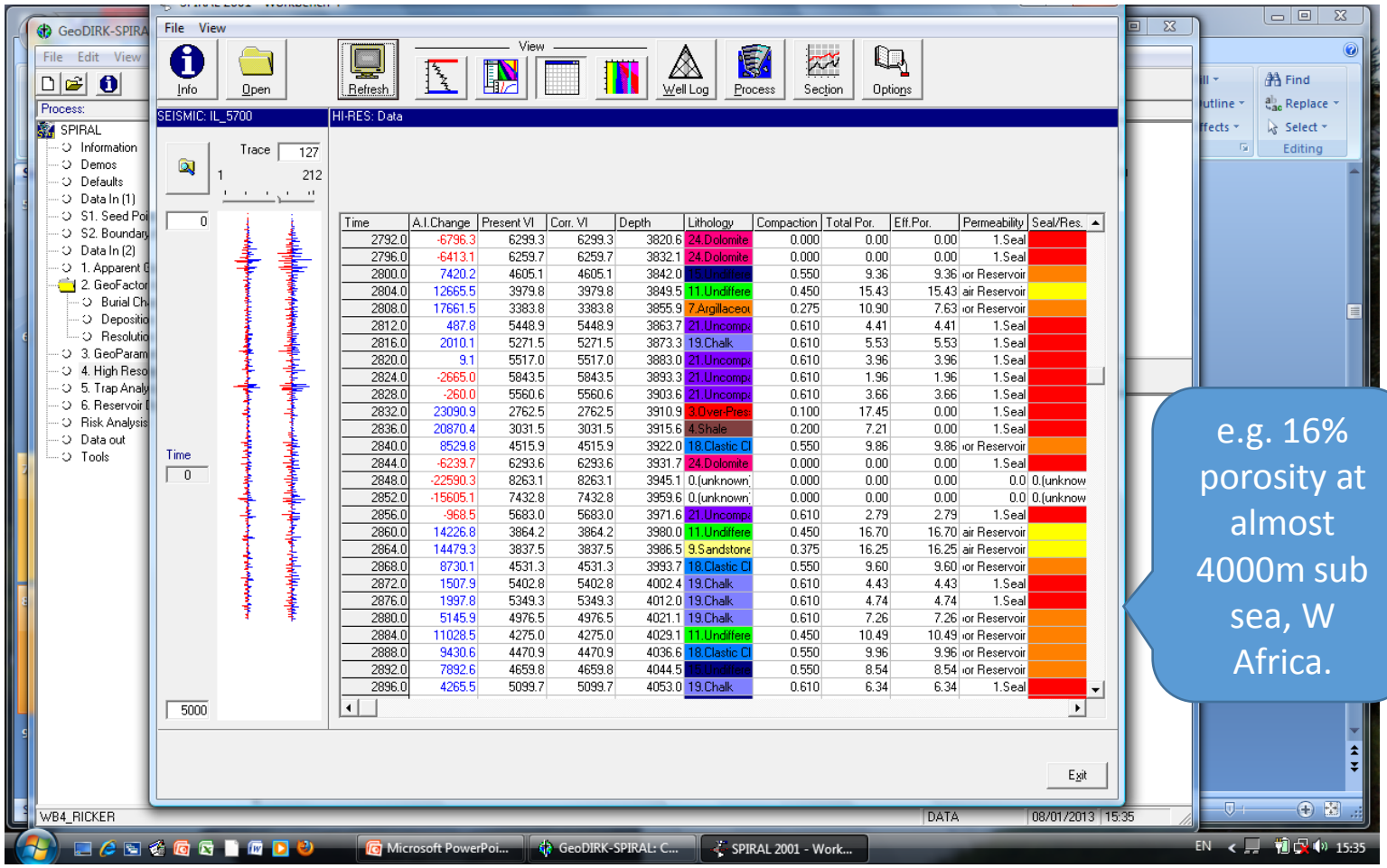
Poro-perms to seals & reservoirs

- Picture of seal – reservoir properties, from X-plot of trace sample poro-perms.



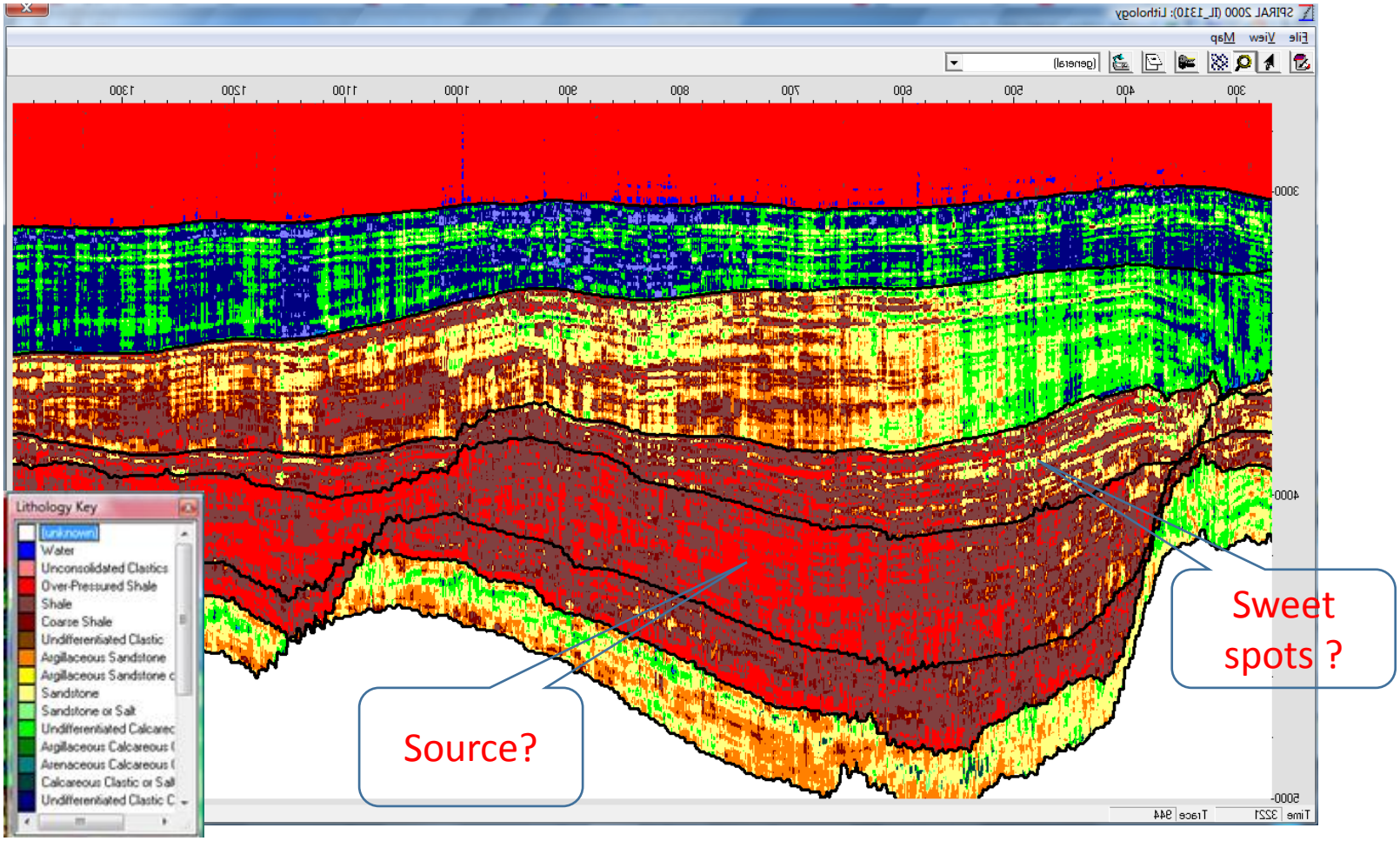
W/b 4 pseudo comp log

from every seismic trace, i.e. 80 x 80 per km2
(all of which are constrained by rules to make integrated G&G&P sense).

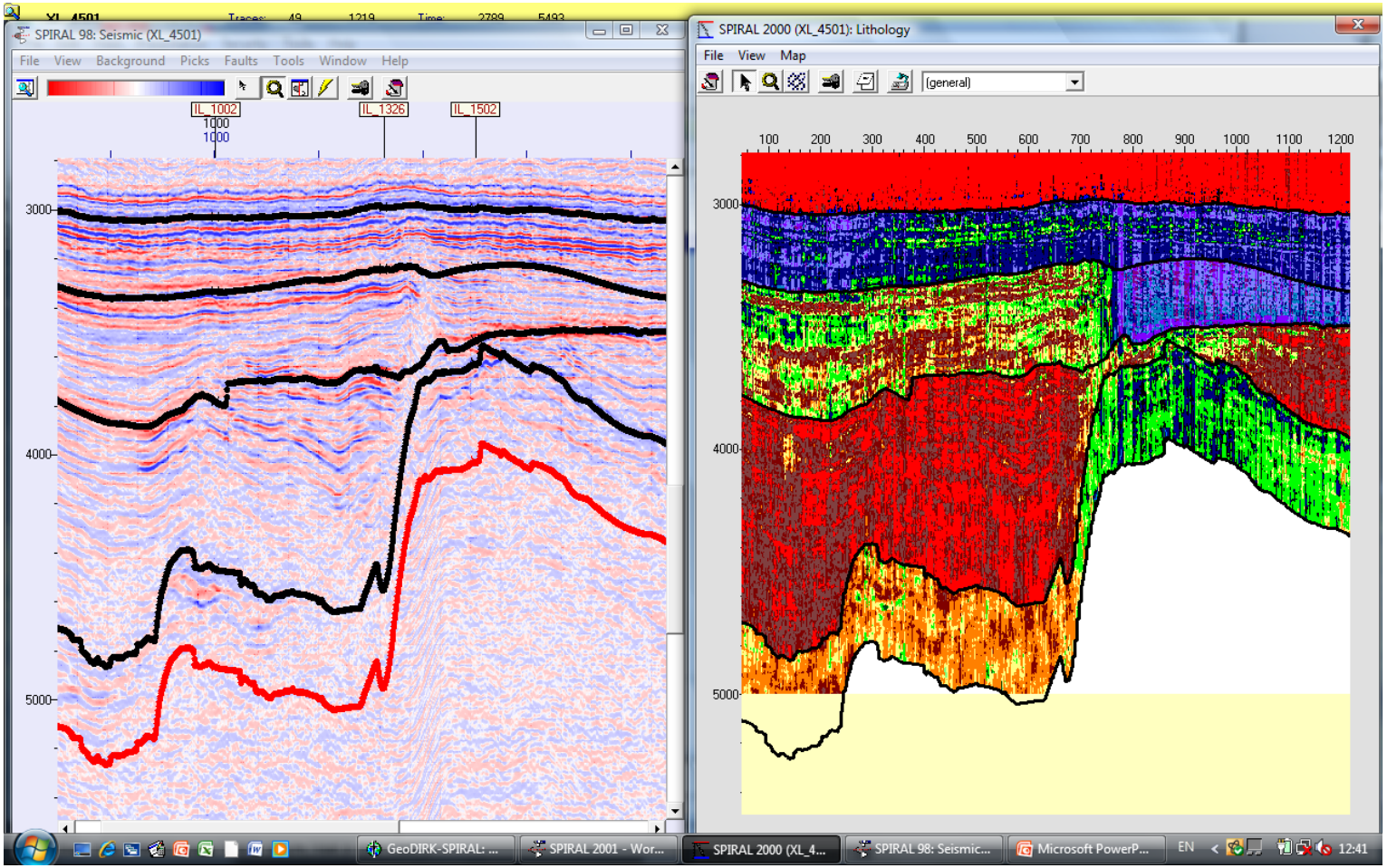


e.g. 16% porosity at almost 4000m sub sea, W Africa.

Run 1, Phase 1 velocities & sequences

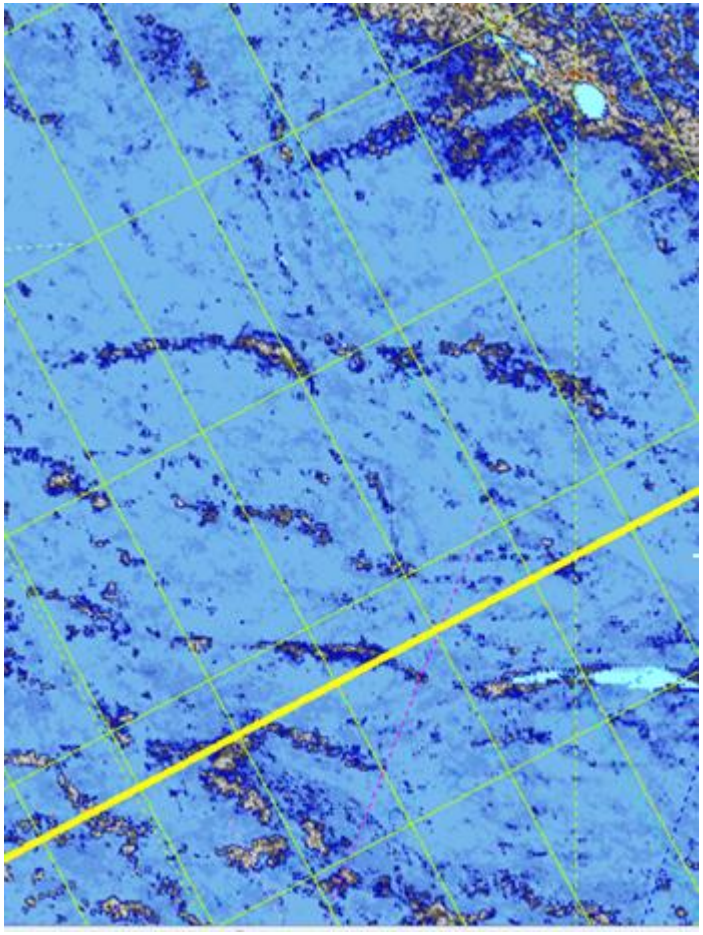


Processing sees (my) Chalk mis-pick



Mudstone seal above flattened top reservoir. About 4.5km depth

1.25 x 2.5 km



Viewed in Petrel with different colours/ lithology

v fine clastic

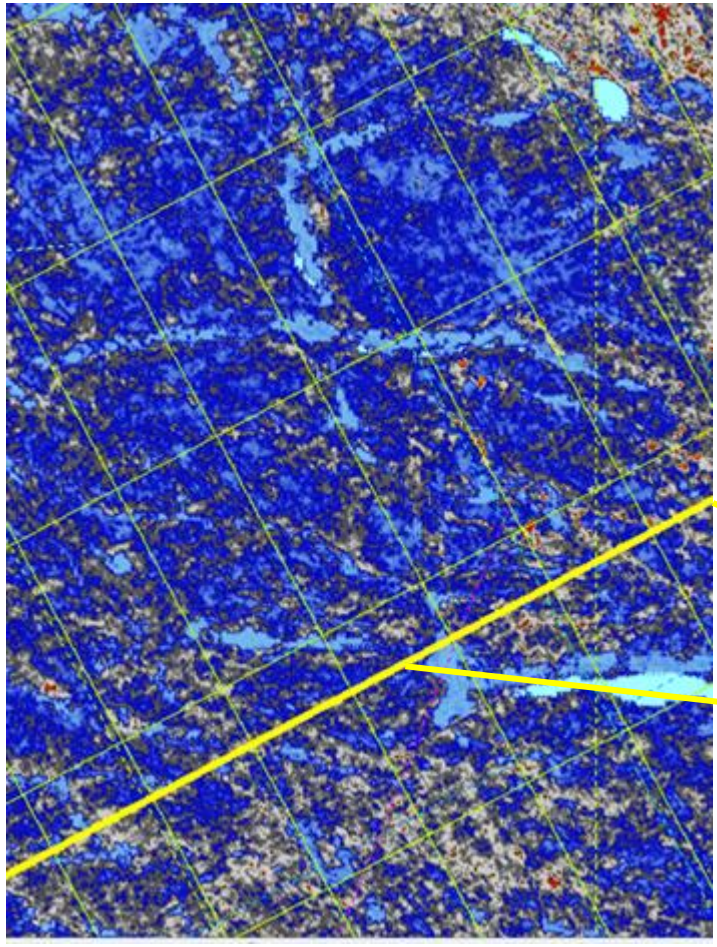
coarser clastic

marl, Lst

tight rocks

16ms/ 33m below top reservoir

1.25 x 2.5 km



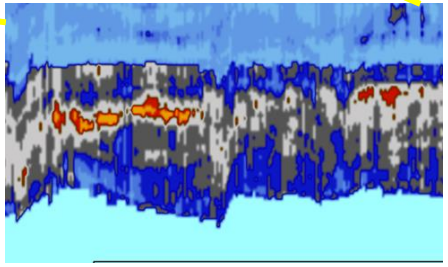
aim for dark blue

v fine clastic

coarser clastic

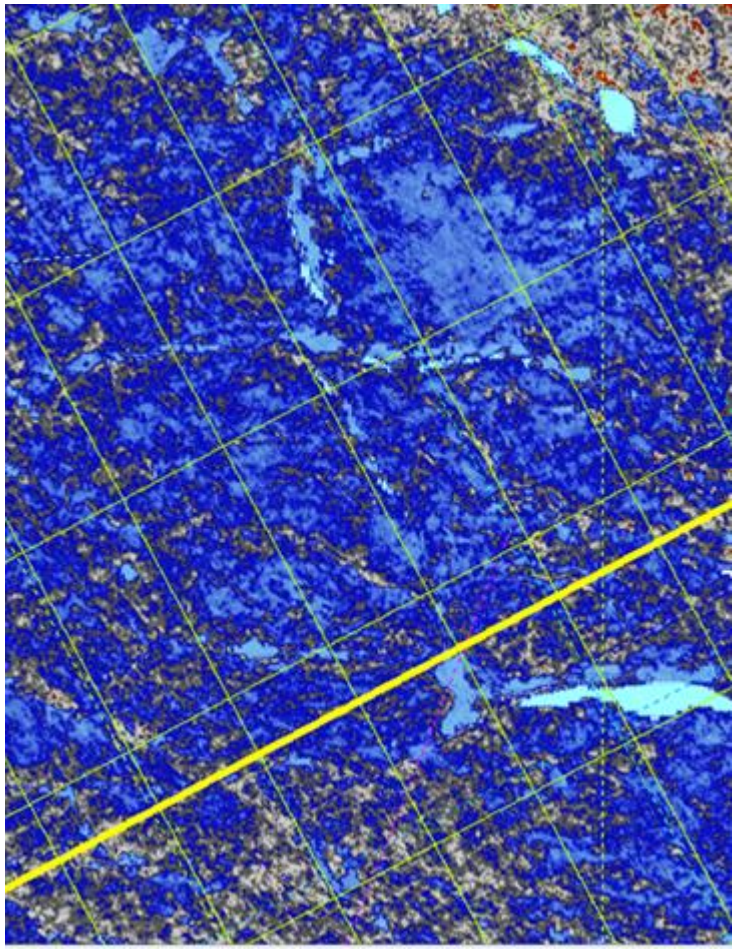
marl, Lst

tight rocks



24ms/ 50m below top reservoir

1.25 x 2.5 km



aim for dark blue

v fine clastic

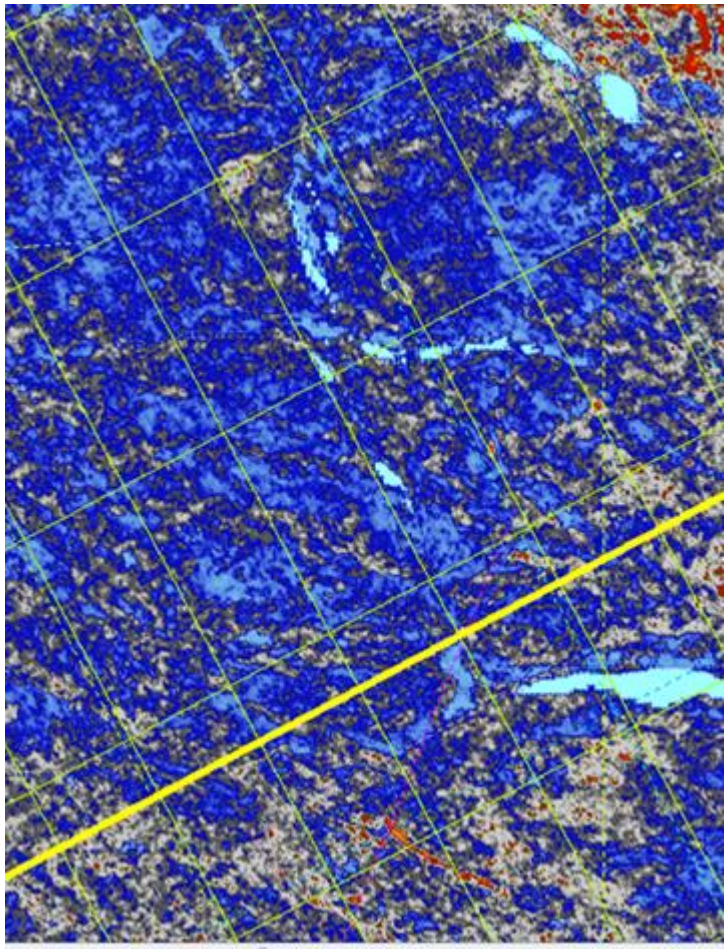
coarser clastic

marl, Lst

tight rocks

36ms/ 76m below top reservoir

1.25 x 2.5 km



aim for dark blue

v fine clastic

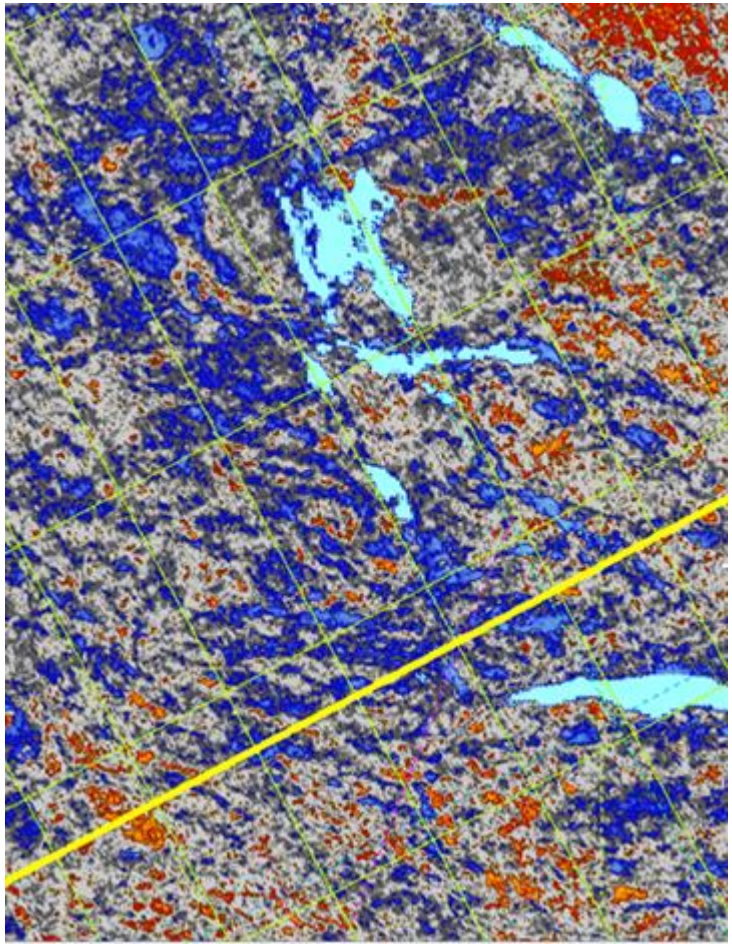
coarser clastic

marl, Lst

tight rocks

56 ms /118m, sub reservoir top into volcano-clastics

1.25 x 2.5 km



aim for dark blue

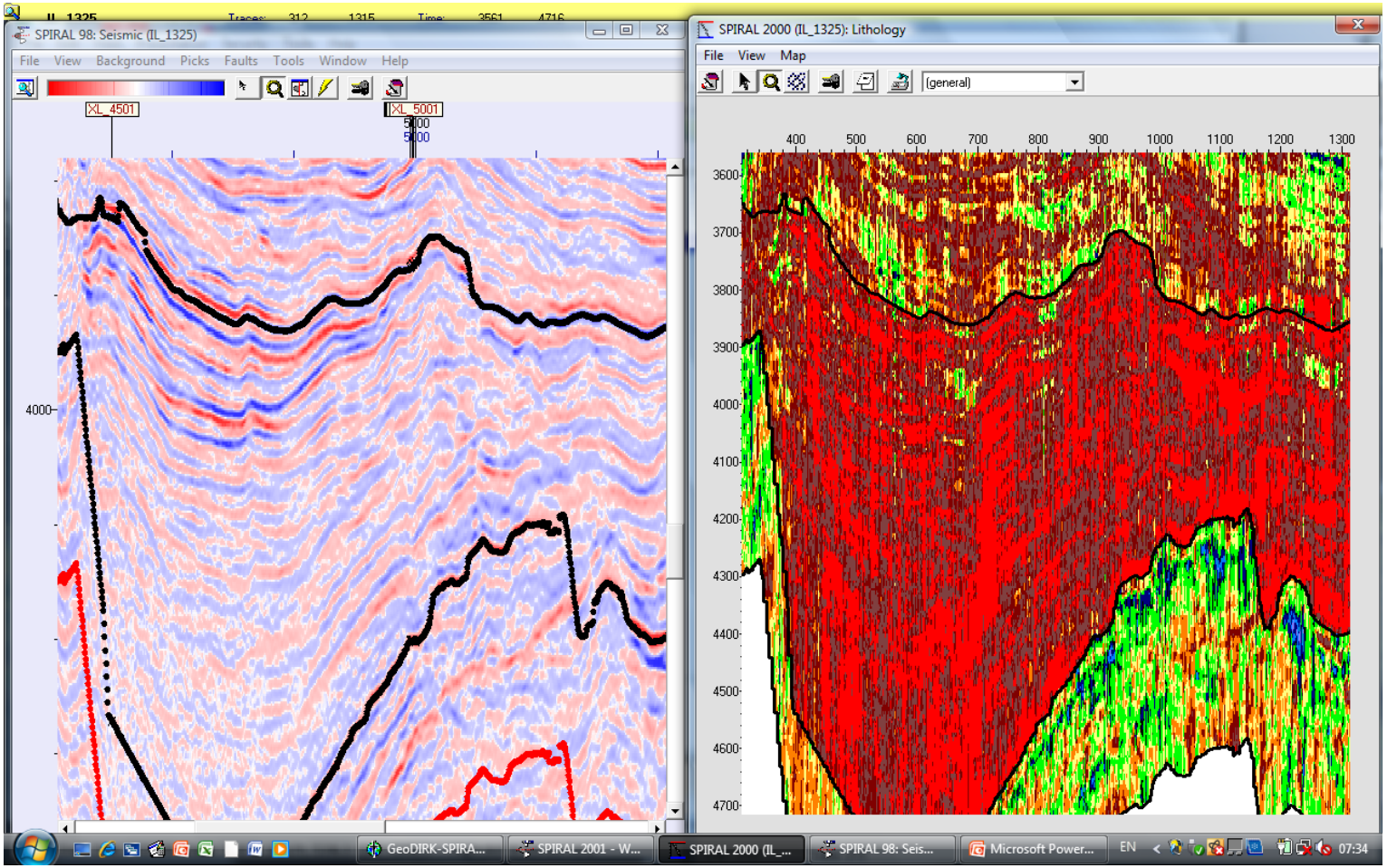
v fine clastic

coarser clastic

marl, Lst

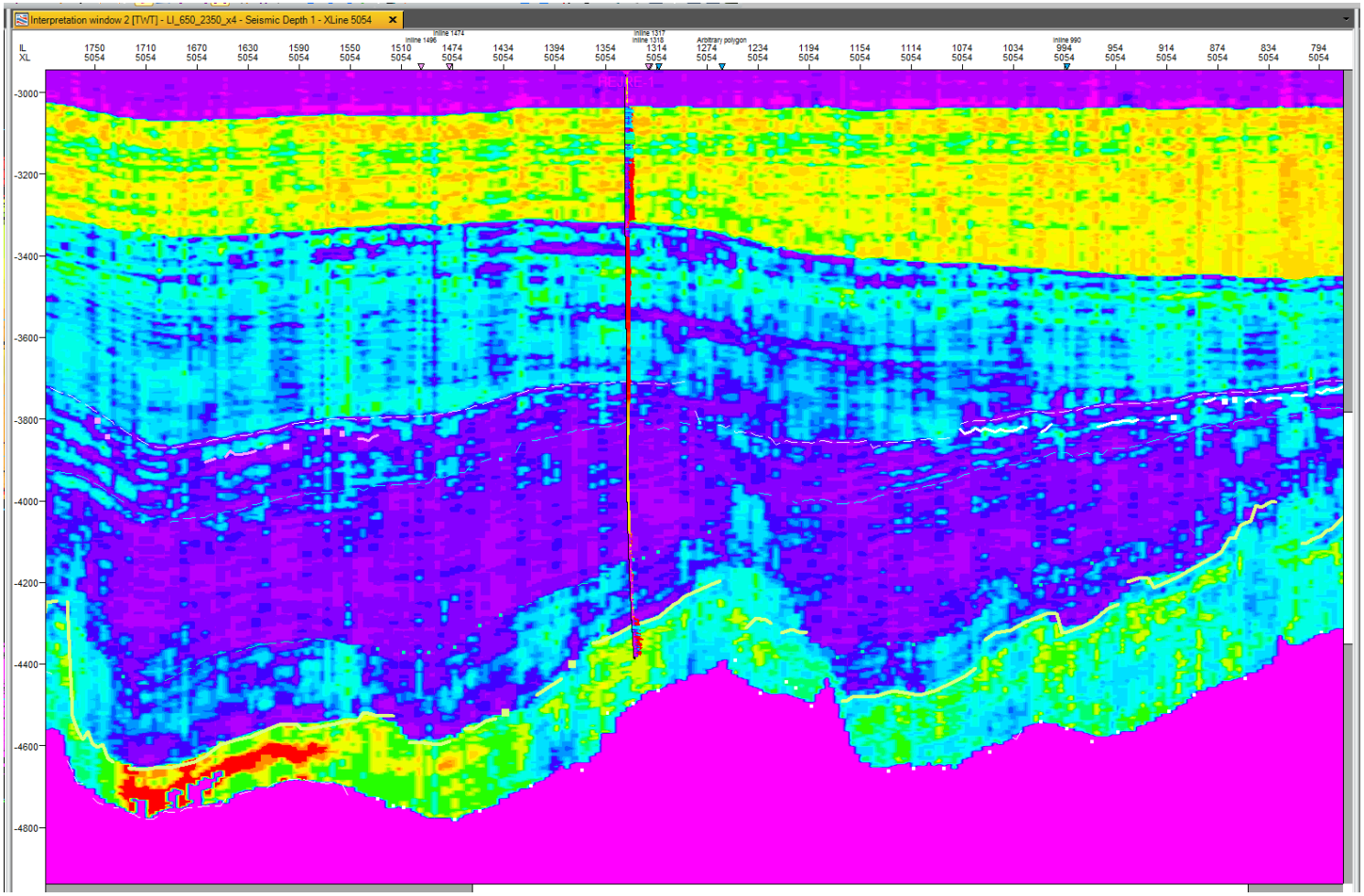
tight rocks

Variations in source/ seal + sweet spots



Back in Petrel, Well shows 2 zones of effective porosity.

Red (Permian?) Plots as 6000m/s, Anhydrite or probably igneous, grading laterally to volcano-clastic

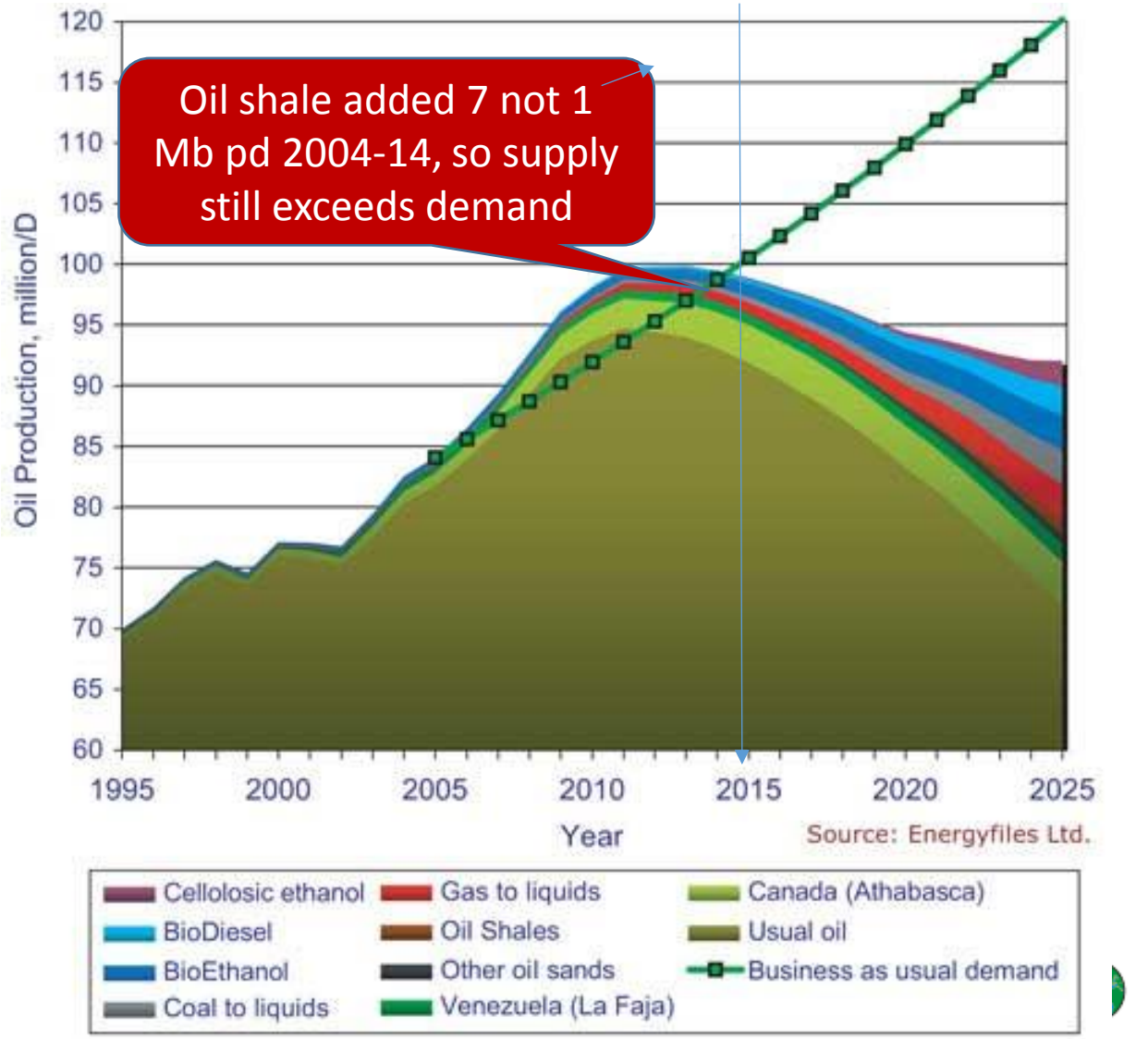


Last chance to increase acreage portfolio before 'Peak Oil'.

(Paper at Society of Petroleum Engineers, R&D conference 04/07)

Estimate of future oil production showing the decline in conventional oil with shortfall *(partly)* made up by unconventional hydrocarbons and synthetic sources.
From paper 'Technology for a Sustainable Tomorrow'
by Vik Rao, Senior VP and Chief Technology Officer, Halliburton.

Note 1: for 100 years, oil demand = population increase.
Note 2: >50% of usual oil comes from a few 'ooo big, old fields, declining at 6% p.a. says IEA.



Drive geo-petro normalisation from your desk-top.

- Download project to GeoDirk processor
  - seg-y, processing velocities, sequence boundary files, well sequence property & geometry data.
- Confirm/ adjust processing parameters per processing stage online, QC output as input to next stage. Up load.
  - Sequence geometry model, assuming local normal burial
  - Sequence local normal geo-petro model
  - Sequence geometry/ geo-petro model, adjusted for localised burial- digenesis controls. Define ΔD to equilibrate to normal.
  - Trace sample / integrated with sequence controls
    - AI, Vint, Vo + KN +/- Vint of KA, lithology, poro-perms etc
  - Seal base geometry, trap GRV, rework fluids, properties,
    - Per Trap, GRV, NRV, rock geology & properties for simulation.

Fit with other seismic post, (pre) stack processing, inversion, EM etc

- The main risk associated with QI quantitative interpretation processing of seismic to poro-perms, fluids etc. is potential for spatial changes in lithology, relative to model used.
  - Suggestion: geo-normalise seismic + outcrop analogues.
- Generation of a more detailed inter-well geologic model, plus conversion to lithology, poro-perms etc.,
  - Focuses other QI processing to volumes of E&P potential
  - Provides input to the model used in required QI processing.
- EM delivers evidence of oil, gas presence,
  - Location is approximate, and permeability needs to be known.

Generating most probable geo or petro model for simulation

- Take a bell curve from many simulations of possible distributions of geo, petro data from well data + seismic sequence shapes.
- Doubling inter-well geo, petro data by integrated seismic normalisation will almost certainly reshape, reposition bell curve derived as above.
  - Objective, robust, easy to understand & QC way to do this is by shifting up & down, best fit of ΔDepth used in cellular processing

The 80-20 rule & how you evolve step change rules & tools

- 20% of the work is done, establishing the rules (IP) & tools (look & feel of IT©). The framework works.
  - Accuracy of output tends to be around 80%, at a few man weeks processing per project per month.
- 80% of extra work should be done to enhance the rules and tools of E&P REIT geo-normalisation
  - Then you can increase current levels of accuracy and rate of worked deliverables, building your group edge.
- Opportunity exists for 5 companies to benefit from 1st user advantage, each working say 5 projects p.a.

Serving geo- petro normalisation

- You generate quality seismic plus sequence boundary time, velocity, depth, and well datasets.
- At 12.5m3, 3D seismic gives good velocity. Know geology in numbers summing lithology and compaction/ digenesis, and we should sensibly compute poro-perms. Errors mapping cellular lithology, upon which poro-perm prediction is risk contingent, is E&P's key cause of inefficiency.
- Geo-normalisation enables expert staff to drive rule based expert systems to integrate geophysics with geology, and petro-physics via processing, so oil company experts can work together more productively and focus their experience on E&P play, prospect and field analysis.
- DON'T focus expenditure on quantifying project geology and associated petro physical, play and field parameters, from local well data alone, as if this describes potential for cellular properties.
- DO focus on increasing objectivity and efficiency of use of quantitative interpretation, seismic +/- well data, (& outcrop analogies) to geo- petro normalise data relative to an in-house QC'd generic standard.
- Work G&G more efficiently, and make E&P drilling & facility engineering cost more efficient, by controlling inter-well poro-perm models, via sensible seismic cellular geological modelling.
- Email info@geodirk.com to access G&G support and use of expert systems, to normalise inter-well seismic data to sensibly fit well based geo and petro models in an optimised, repeatable uniform manner, so you can work up more, lower cost and risk, E&P opportunities.

Geological normalisation of seismic.

*In theory, it doubles G&G productivity, to cut E&P cost & risk by 15% *: Practice, in >50 projects (all geologic systems), tends to prove theoretical potential.*

- Prime cause of E&P inefficiency is wrong inter-well forecast of poro-perms, largely risk contingent upon knowing geology as causes spatial property change.
- G&G defines geology via well and sequence shape models, then simulates potentially compounded variations caused by (some 15 factorial) changes in sedimentation, lithofacies and /or structural geology, compaction, digenesis, fluids etc.
- To significantly enhance E&P success requires processing of seismic into better geologic, then poro-perm, and fluid models. Plus similar normalisation of rock outcrop analogies.
- Seismic now provides relatively accurate pseudo sonic log, time, velocity, depth data per 12.5m trace, at <12.5m vertical. P & S velocity data can be gathered pre stack. Seismic provides excellent seismic stratigraphic shapes, potentially enabling quantitative interpretation (QI) to better define geology of deposition and burial changes.
- Where inter-well cells compact normally relative to well data, conversion to inter-bedded lithologies and their poro-perms should be low risk. Therefore, normalisation, per seismic volume having similar burial compaction controls, allows equilibration by depth shift, with well based ‘normal’ depth compaction. This allows conversion of seismic to geo and petro information that is risk dependent primarily on quantification of burial depth equilibration shift.
- Expert geo-detectives need to re-focus seismic +/- well data to filter presence / absence of such geo-causes of property change, relative to burial-change ‘norm’ then generate a normalised, single most probable geo-petro model. QI filters cellular data to quantify separate and net effects of causes of burial changes. Then, cellular seismic numbers = cellular geologic numbers of deposition and burial changes = cellular petro-physical numbers, in one, most probable, harmonious, multidisciplinary integration, containing presence / absence of geo-risks.
- Integrating, analysing, visualising and correctly interpreting extra multi-disciplinary measurements goes beyond desktop applications available today. So, we beta tested, in > 30 data sets each >600km3, ‘apps’ to process cellular evidence crucial for geo-detection, for current workstations.

(* Independent UK State commissioned evaluations of KA’s patents)