Heterogeneity

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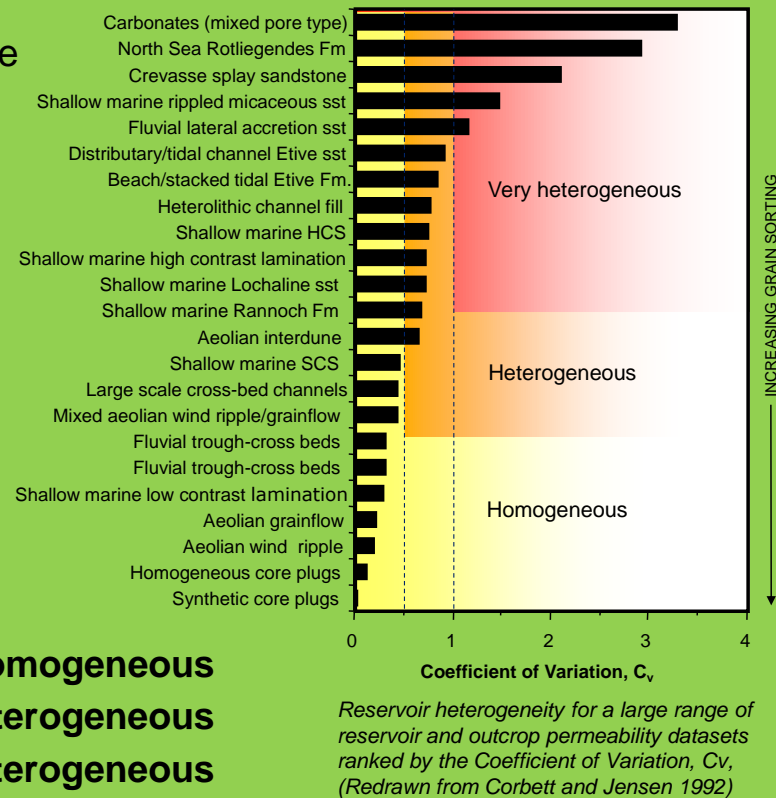
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Heterogeneity in reservoirs is usually understood to mean permeability heterogeneity, although in carbonates, porosity can also sometimes also be considered heterogeneous

Heterogeneity can be defined by the **Coefficient of Variation (Cv)**
Cv is standard deviation divided by arithmetic average

Carbonates (mixed pore type)
North Sea Rotliegendes Fm
Crevasse splay sandstone
Shallow marine rippled micaceous sst
Fluvial lateral accretion sst
Distributary/tidal channel Etive sst
Beach/stacked tidal Etive Fm.
Heterolithic channel fill
Shallow marine HCS
Shallow marine high contrast lamination
Shallow marine Lochaline sst
Shallow marine Rannoch Fm
Aeolian interdune
Shallow marine SCS
Large scale cross-bed channels
Mixed aeolian wind ripple/grainflow
Fluvial trough-cross beds
Fluvial trough-cross beds
Shallow marine low contrast lamination
Aeolian grainflow
Aeolian wind ripple
Homogeneous core plugs
Synthetic core plugs

Very heterogeneous
Heterogeneous
Homogeneous

INCREASING GRAIN SORTING

Coefficient of Variation, C_v

Reservoir heterogeneity for a large range of reservoir and outcrop permeability datasets ranked by the Coefficient of Variation, Cv, (Redrawn from Corbett and Jensen 1992)

Cv < 0.5	**Homogeneous**
0.5 < Cv < 1.0	**Heterogeneous**
Cv>1.0	**Very Heterogeneous**

Heterogeneity Workflow – Coefficient of Variation

- Look at the carbonate interval (usually a bed)
- **Does it look uniform? YES**
- Collect some data (25 samples)
- Calculate Cv for porosity and permeability
- The porosity Cv is usually <0.5
- If the permeability Cv is < 0.5
- **Homogeneous confirmed**
- Relax and use any average for the properties

Step 1

- Look at the carbonate interval (usually a bed)
- **Does it look uniform? NO**
- Collect some data (100 samples)
- Calculate Cv for porosity and permeability
- The porosity Cv is usually <0.5 (but might be slightly higher)
- In carbonates the permeability Cv is likely > 1.0 (if between 1 and 0 – heterogeneous)
- **Very Homogeneous confirmed**
- You cannot relax – averages all different – so you need to do more analysis

Step 2

- Look at the carbonate interval (usually a bed)
- Permeability Cv > 1.00 (Porosity Cv may be greater than 0.5)
- **You have a real sampling challenge.**
- If Cv is close to 1:0 calculate $10Cv^2$
- This will given number of samples to estimate average permeability within +/- 20%
- Or you can collect some more samples and establish average +/-20% and reasonable Cv
- If Cv >> 1 you probably need to switch to **carbonate sampling criteria** $4Cv^2$ to allow you to establish average +/-50% (Cv might not be great!)
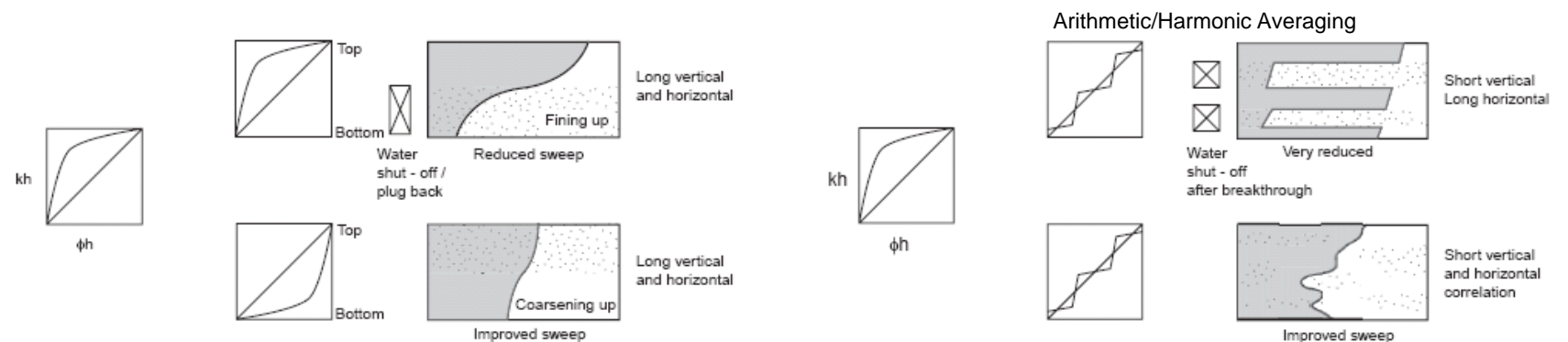
Step 3

The **Lorenz Plot** (LP) is a normalised cross plot of cumulative porosity thickness versus cumulative permeability thickness for an ordered (high to low) set of core plugs. Modified (also Unordered) LP is the same data but in stratigraphic order

Steps 1-3 allow you to get a handle on estimating average bulk permeabilities with some known degree of accuracy in carbonates

Steps 4-5 allow you to identify the spatial patterns in very heterogeneous carbonates and provide additional diagnostics (even whether the reservoir is fractured or not)

Step 4

Heterogeneity Workflow - Lorenz Plots and PLT

- The Modified Lorenz Plot and can be compared with the Spinner Survey (PLT)
- NB: To do this you need to rotate the axes of LP (porosity feet – when porosity is quite uniform – corresponds to feet/depth)
- **MLP shows same inflow zones as PLT** – then it is the **matrix** that is flowing (crossflow or commingled?)
- **MLP shows no correspondence with PLT** - then the reservoir might well be **fractured**
- NB: Fracture property information is seldom captured in the core plugs which are basis for Lorenz Plots

Step 5

Heterogeneity Workflow – Lorenz Plots

- The Lorenz Plot and Modified Lorenz Plot are used together (NB: these are matrix property plots)

kh
φh
Top
Bottom
Fining up
Long vertical and horizontal
Water shut - off / plug back
Reduced sweep

Top
Bottom
Coarsening up
Long vertical and horizontal
Improved sweep

Arithmetic/Harmonic Averaging
Short vertical Long horizontal
Water shut - off after breakthrough
Very reduced

Short vertical and horizontal correlation
Improved sweep

Geometric Averaging

- **Sometimes large scale natural ordering is seen – and sometimes there is small scale or no ordering**

NB: The semivariogram in the vertical direction can also help determine random vs ordered or repeating

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